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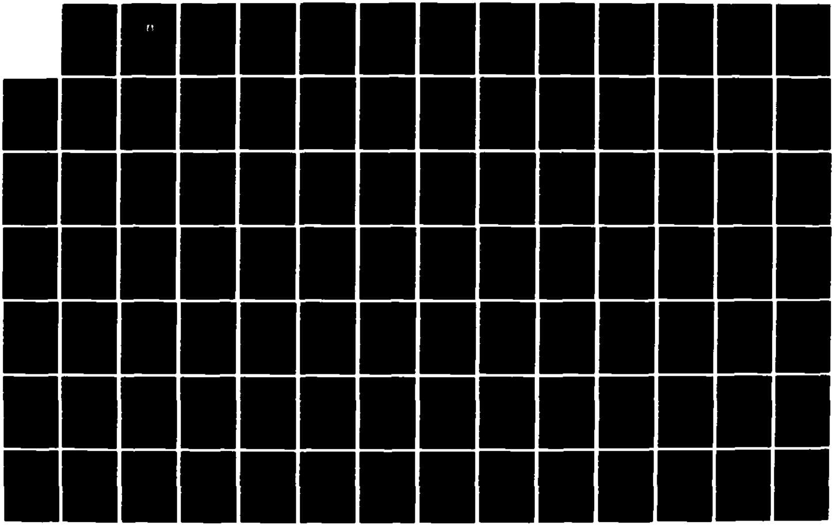

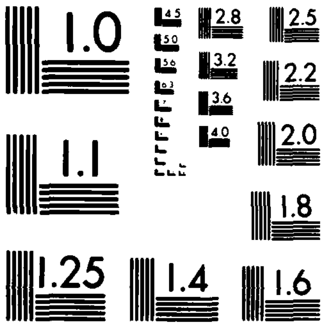

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FOREIGN TECHNOLOGY DIVISION

DYNAMICS OF RAREFIED GAS AND MOLECULAR GAS DYNAMICS

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DYNAMICS OF RAREFIED GAS AND MOLECULAR GAS DYNAMICS

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

DYNAMICS OF RAREFIED GAS AND MOLECULAR GAS DYNAMICS.

Page 2. (No Typing).

AERODYNAMIC CHARACTERISTICS OF BODIES IN THE TRANSITION REGION AT HYPERSONIC SPEEDS OF FLOW.

V. N. Gusev, T. V. Klimova, A. V. Lipin.

SUMMARY.

Is conducted the analysis of the special features/peculiarities of the hypersonic flow around bodies in the transition region, which lies between the region of free molecular flows and the zone of flow of gas as continuous medium. Are discussed questions of the simulation of actual conditions in the transition region on the basis of the vast experimental material, obtained in the low-pressure wind tunnel of TsAGI [ЦАГИ - Central Institute of Aerohydrodynamics im. N Ye Zhukovskiy]. Work gives the aerodynamic characteristics of the broad class of bodies.

ADOPTED DESIGNATIONS.

c_i - aerodynamic coefficient;

$c_x = \dfrac{x}{\dfrac{\rho_\infty U_\infty^2}{2} S}$ - drag coefficient;

$c_y = \frac{y}{\frac{\rho_\infty U_\infty^2}{2} S}$ - lift coefficient;

d - diameter of blunting;

D - diameter of maximum cross section;

$K = c_y/c_x$ - lift-drag ratio;

$m_z = \frac{M_z}{\frac{\rho_\infty U_\infty^2}{2} SL}$ - coefficient of pitching moment;

n - exponent in law $\mu \sim T^n$;

Pr - Prandtl number;

Re_0 - Reynolds number, in whom the coefficient of viscosity/ductility/toughness is calculated from the temperature of stagnation,

$$Re_{0L} = \frac{\rho_\infty U_\infty L}{\mu_0}; \quad Re_{0l} = \frac{\rho_\infty U_\infty l}{\mu_0}; \quad Re_{0D} = \frac{\rho_\infty U_\infty D}{\mu_0};$$

S - area;

T_0, T_w - temperature of stagnation and the temperature of body surface;

U_∞ - speed in the undisturbed flow;

α - angle of attack;

α_{max} - angle of attack when $K = K_{max}$;

γ - specific heat ratio;

θ - half-apex angle of the cone and semicone;

δ - thickness of plate,

$$\bar{\delta}_L = \delta/L; \quad \bar{\delta}_l = \delta/l;$$

λ - elongation of plate, equal to the ratio of its width to the chord in the root section;

χ - sweep angle;

ρ_∞ - density in the undisturbed flow;

μ - coefficient of viscosity/ductility/toughness;

μ_0 - coefficient of viscosity/ductility/toughness with $T=T_0$.

Indices "t" and "n" designate respectively wind tunnel tests and full-scale.

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Introduction.

The technical progress in aviation and rocket engineering led to the intense development of theoretical and experimental studies in the region of aerodynamics of hypersonic flows. The greatest number of these investigations relates to two sufficiently to well studied regions of general gas dynamics. One of them - this is usual gas fluid dynamics in which the characteristic mean free path of molecules is much lower than the significant dimension of body. The detailed presentation of the theory of hypersonic flows in this region with its numerous applications/appendices is contained in monographs [1, 2]. Another region - dynamics of the free molecular and adjacent it medium where the course of gas proves to be such rarefied that the characteristic mean free path of molecules becomes much more than the significant dimension of body. Latest achievements in this region are presented in monograph [3]. Are least investigated flows of rarefied gas in the intermediate transition region. A strict theoretical studies of such courses can be carried out only on the basis of kinetic theory, which uses an equation of Boltzmann. The solution of this equation is at present connected with the great mathematical difficulties.

Not easy here proves to be the experimental path. Creation of hypersonic low-density flows, their diagnostics and conducting in them experimental investigations - most complex task of contemporary experimental aerodynamics of hypersonic flows. At present on one experimental installation it is not possible to carry out complete simulation during model tests in hypersonic flow, since besides Mach numbers and Re in the wind tunnel it is necessary to reproduce the high value of the enthalpy of hypersonic flows. The coincidence of these conditions in one installation/setting up is extremely difficult. In connection with this experimental research of hypersonic flows divide into the investigations of the effects of hydrodynamic character, caused by change Mach numbers and Re, and investigation of the effects of imperfect gas, caused by high energy of flow. To the discussion of hydrodynamic special features/peculiarities indicated above of the hypersonic flow around bodies in the transition region, which lies between the region of free molecular flows and the zone of flow of gas as continuous medium, and is dedicated this work. In it is systematized the vast experimental material, obtained in the low-pressure wind tunnel of TsAGI.

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Simulation of actual conditions in a transition region [1].

FOOTNOTE [1]. As the basis of this part of the work is assumed V. N. Gusev's report "Problems of simulation in the dynamics of the rarefied gases" at the III All-Union conference on the dynamics of the rarefied gases (Novosibirsk, 1969). ENDFOOTNOTE.

Questions of the similarity of hypersonic flows in the transition region were examined in work [4]. On the basis of the equation of Boltzmann in it it is shown that under the power law of interaction of molecules for observing the similarity in the mode/conditions of hypersonic stabilization besides the geometric similarity it is necessary to maintain/withstand the equality of the following parameters: Reynolds number Re_0, in whom the coefficient of viscosity/ductility/toughness is calculated from the temperature of stagnation, exponent n in the dependence of the coefficient of viscosity/ductility/toughness on temperature $\mu \sim T^n$, temperature factor T_w/T_0, where T_0 and T_w - respectively the temperature of stagnation and body surface, specific heat ratio γ, number of Prandtl Pr and coefficient of accommodation. Of the parameters mentioned, the Re_0 number it is basic similarity criterion: with its change the values of the aerodynamic characteristics of the streamlined body

can change to the orders.

When $T_w/T_0=1$ basic laws governing the supersonic flow around characteristic bodies over a wide range of a change in criterion Re_0 were revealed in work [4]. Data for the transient region were obtained in the low-pressure wind tunnel employing the presented in work [4] procedure. For the zone of flow, close to free-molecular, when is applicable the theory of the first intermolecular collisions, the aerodynamic characteristics of bodies were obtained by calculation [5, 6]. Experimental data for the case of viscous flows of continuous medium were borrowed from works [7, 8], theoretical - from works [9, 10]. For the cone with the half-angle of solution/opening θ and plate whose relative thickness $\delta/L=0.03$, these data are cited in Fig. 1-6. During the calculation of aerodynamic coefficients as the characteristic area was selected the area of body S in the plan/layout; pitching moment m_z was calculated relatively "nose/leading edge"; through α was designated the angle of attack.

As it follows from given data, the results of experiment and calculations according to the theory of the first intermolecular collisions and according to the theory of the viscous flows of continuous medium make it possible to obtain information in the entire transient zone of flow. In this case experimental and theoretical data, obtained taking into account the parameter of similarity Re_0, will agree sufficiently well with each other.

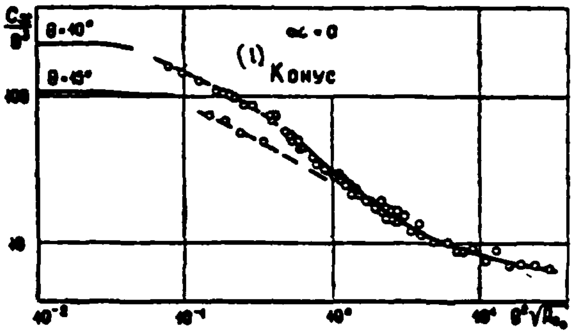

Fig. 1.

Key: (1). Cone.

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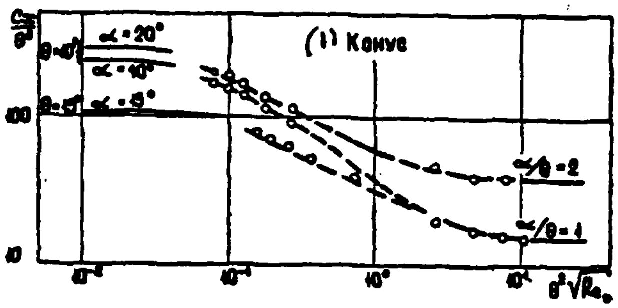

Fig. 2. Key: (1). Cone.

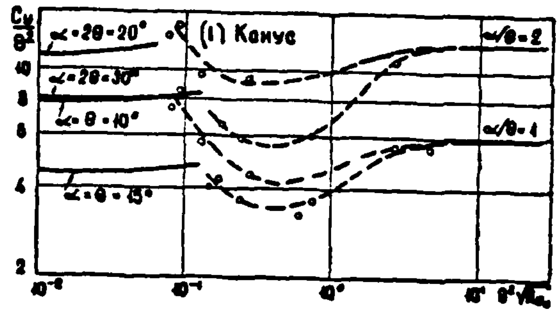

Fig. 3. Key: (1). Cone.

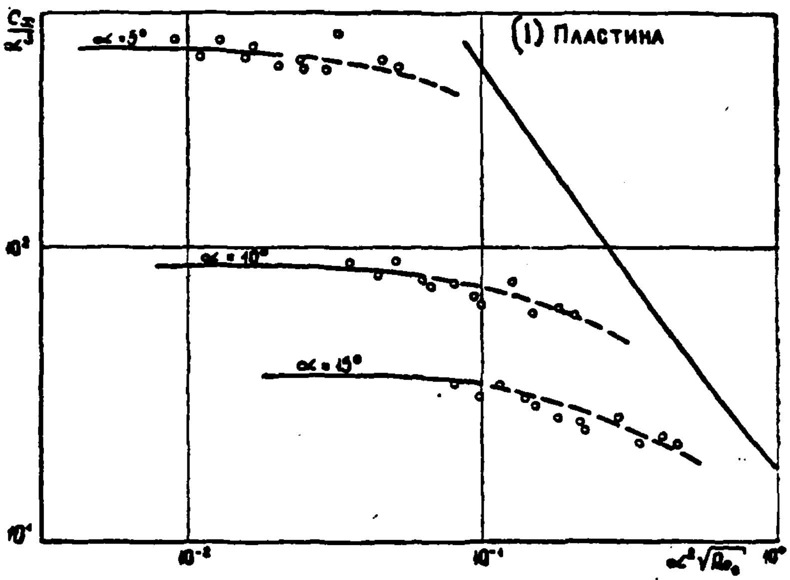

Fig. 4. Key: (1). Plate.

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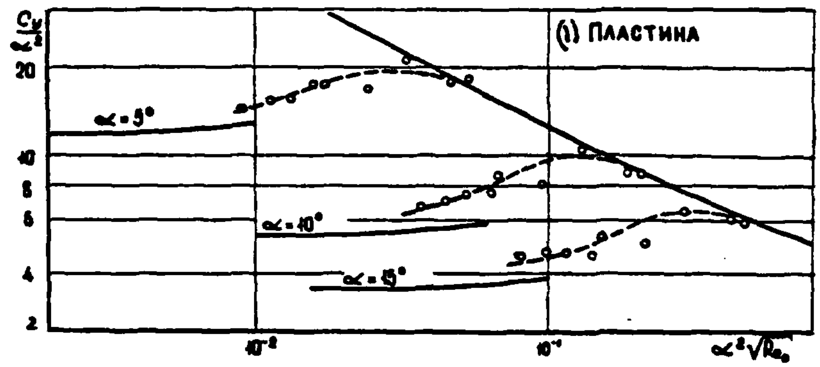

Fig. 5. Key: (1). Plate.

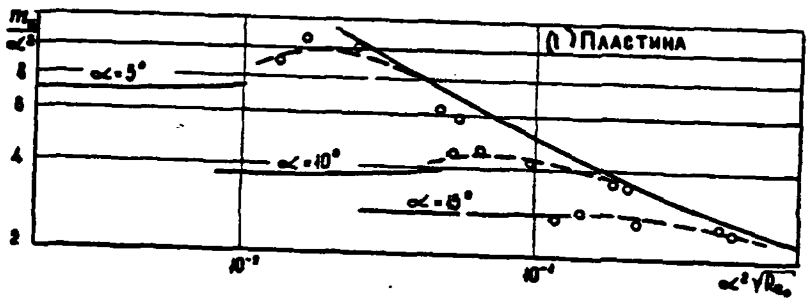

Fig. 6. Key: (1`. Plate.

Should be focused attention on the nonmonotony of a change of some characteristics in the transition region where their values prove to be more than the values, obtained in the free molecular flow, and in certain cases except the maximum indicated they have even and a minimum (for example, the coefficient of lift force of cone). All this speaks, that the laws of the behavior of aerodynamic characteristics in the transition region are very complicated and they cannot be obtained by simple interpolation of given for

continuous medium and free molecular courses.

During the simulation of actual conditions in the wind tunnels besides the basic criterion of similarity Re, it is necessary to maintain/withstand a whole series of other important similarity criteria. However, the installations/settings up existing at present in which the temperature of stagnation is close to the room, by no means provide this simulation. In connection with this arises the question about the procedure of the recalculation of the results of tube experiment for the actual conditions with the noncoincidence of some similarity parameters. In the case of the thermodynamically ideal gas these parameters include T_w/T_0, by n, γ, a number of Prandtl, accommodation coefficients. As are shown available in works [11, 12] data, under the conditions of the viscous hypersonic flows at the speeds of less or the order of the first space, effects of imperfect gas to the aerodynamic characteristics are insignificant, and air can be considered as the thermodynamically ideal gas.

It is known that for air at low temperatures ($T<150°K$) $\mu \sim T$, i.e., n=1, and with $T>400°K$ value n is close to 0.67. In other words, at low temperatures of the molecule of air they behave as Maxwellian, i.e., with large T they are nearer to the elastic spheres.

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Therefore obtained in the low-temperature wind tunnels data cannot be transferred to nature, even if we ensure a sufficient cooling of models for obtaining the full-scale values T_w/T_0.

For the courses, close to the free molecular ones, a question about the recalculation of tube data to the full-scale ones was examined in monograph [3]. In the region of viscous hypersonic flows for this purpose was applied the approximate law of similarity of Cheng [11, 13]. The detailed analysis of the effect of different similarity criteria on the aerodynamic characteristics of simple bodies in this region is given in works [14-16]. The results represented in them of the parametric analyses of the flow around the simplest bodies make it possible to explain the degree of the nearness of the aerodynamic characteristics, obtained under the wind tunnel and the actual conditions, and in certain cases [14] to introduce the appropriate corrections during the complete simulation on criteria T_w/T_0, n, γ.

It is possible to attempt to find the approximate laws of simulation with the aid of the experimental data (for example, see [17, 18]). In this case one should only have in mind that the boundary of free molecular hypersonic flows and the aerodynamic

characteristics of bodies in such flows depend on the form of body, temperature of its surface and laws of interaction of the molecules between themselves and body surface [3].

Let us present arbitrary aerodynamic value c_i in the form

$$c_i = c_{i\infty} + (c_{i0} - c_{i\infty}) f\left[\mathrm{Re}_0\left(\frac{T_w}{T_0}\right)^\beta, \frac{T_w}{T_0}, n, \gamma, \ldots\right],$$

where $c_{i\infty}$ and c_{i0} - value c_i with $\mathrm{Re}_0=\infty$ and to zero, and β is the function of the similarity parameters and in the general case depends on the shape of body. Relying on experimental data, it is possible to attempt to find such value β, at which the dependence of functions f on the criteria of similarity T_w/T_0 and n will be weak. In this case the data, obtained in the low-temperature wind tunnel, can be converted to the full-scale ones. Actually/really, let c_i^T - obtained in the wind tunnel value of value c_i when $T_w/T_0=1$ and n=1, and c_i^H - corresponding to it full-scale value c_i at fixed value $T_w/T_0 \ll 1$ and n=0.67.

Then

$$c_i^H = c_{i\infty}^H + (c_{i0}^H - c_{i\infty}^H) f\left[\mathrm{Re}_0^H\left(\frac{T_w}{T_0}\right)^\beta, \gamma, \ldots\right],$$

where

$$f\left[\mathrm{Re}_0^H\left(\frac{T_w}{T_0}\right)^\beta, \gamma, \ldots\right] = f[\mathrm{Re}_0^T, \gamma, \ldots] = \frac{c_i^T - c_{i\infty}^T}{c_{i0}^T - c_{i\infty}^T},$$

$$\mathrm{Re}_0^H\left(\frac{T_w}{T_0}\right)^\beta = \mathrm{Re}_0^T.$$

It is obvious that with this recalculation it is necessary to know values c_{i0} and $c_{i\infty}$ obtained under the wind tunnel and the actual conditions. The latter can be determined by calculation.

For the drag coefficient of sphere and cone the identification of parameter β was produced on the basis of experimental data, given in the works [4, 17]. Analysis showed that with β=-0.1 the experimental values, obtained at the essentially different values of temperature factor, will agree sufficiently well with each other over a wide range of a change in Mach numbers and Re.

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The results of this comparison are given in Fig. 7 and 8. There solid lines gave the results of calculation according to the theory of first intermolecular collisions [5].

It is obvious that approximation method examined above of the recalculation data, obtained in the low-temperature wind tunnels, by the full-scale ones is not strict and cannot encompass entire diversity of bodies and ranges of a change in the similarity criteria. However, the absence at present of a sufficient quantity of experimental data at substantially the higher values of gas enthalpy makes it possible to propose nothing the best. In proportion to the

accumulation of such data this gap/spacing will be eliminated.

It is necessary to keep in mind that in certain cases with the accuracy acceptable for practical purposes there is no need for increasing the temperature of stagnation of flow in the wind tunnel to its full-scale values. For example, the given in work [14] estimations show that in the region of viscous interaction heating gas in the precombustion chamber to T_0=2000° K provides the simulation of the full-scale values of resistance and lift of plate with an error less than 4%, when $T_w/T_0 > 0{,}05$. The latter fact in many respects facilitates the way of the straight/direct simulation of actual conditions in the wind tunnels.

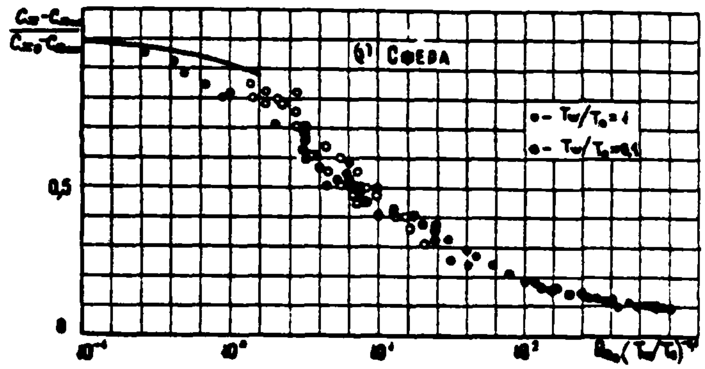

Fig. 7. Key: (1). Sphere.

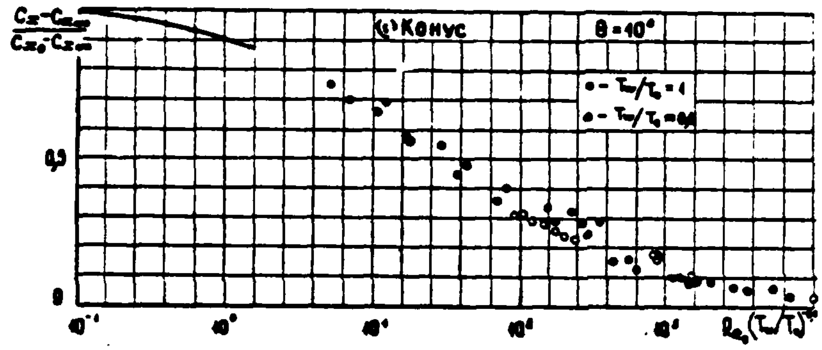

Fig. 8. Key: (1). Cone.

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AERODYNAMIC CHARACTERISTICS OF BODIES IN TRANSIENT ZONE OF FLOW.

The special features/peculiarities of the flow around the bodies of the simplest forms, arranged/located at the arbitrary angle of attack α in the hypersonic low-density flow, were examined in the series/row of the works (for example, see [7], [8], [17], [19] -

[23]). Are represented below systematized experimental data, obtained in the low-pressure wind tunnel of TsAGI. The coefficients of drag c_x, lift c_y, pitching moment m_z and lift-drag ratio K of the broad class of bodies are given in the dependence on the angle of attack α when $T_w/T_0=1$ and n=1. Aerodynamic coefficients are everywhere related to velocity head q and characteristic area S, pitching moment m_z is related to the significant dimension of L and is calculated relative to the end section of model.

Tests were conducted in the low-pressure wind tunnel of TsAGI. For the formation of the supersonic flow served calculated conical nozzle with the aperture angle of 25°. As the working gas was utilized air at a room temperature. A maximum change in Mach number along the length of model did not exceed 2%.

During the determination of aerodynamic coefficients were utilized the values of the parameters of the undisturbed flow at the point, which corresponds to the middle of model. As applied to the low-pressure wind tunnels the procedure of the recalculation of aerodynamic characteristics in the nonuniform flow the not corresponding characteristics in the uniform for some simplest bodies in the maximum modes/conditions of flow is presented in the works [24, 25] For the cone with a half-angle of solution/opening of θ=30° at the angle of attack α=0 the following from work [24] correction to

c_x for the heterogeneity of flow in given conditions of experiments did not exceed 4%. For the cones with the smaller aperture angles it was less.

For measuring of the aerodynamic forces and moments of forces were utilized three-component magnetoelectric weights. The sensitivity of balance comprises the tenths of milligram. A relative error of measurement of forces does not exceed, as a rule, ±2%, the moments of forces - ±5%.

Taking into account errors of measurement of the flow parameters a relative error in the determination of aerodynamic coefficients comprised in the majority of cases of 5-6%. Somewhat greater errors occurred for the models of small sizes/dimensions - they reached 7-10%.

The installation/setting up of symmetrical models relative to the axis of flow was realized with the aid of the mechanism α of weights. Angle of attack α was considered equal to zero when simultaneously they turned into zero normal to the model force and pitching moment. An error of measurement α composed 10'. With the same accuracy the "angular dimensions" of models accepted correspond to real ones.

Cone. The aerodynamic characteristics of the thin pointed cones with different aperture angles ($7° \le 2\theta \le 40°$) at the fixed value of number $Re^{T}_{0L} = 162$, cone designed along the length, are represented in Fig. 9-12. During the calculation of aerodynamic coefficients as the characteristic area S here, as subsequently is selected the area of the basis/base of cone, and as the significant dimension of L - its length.

The analogous characteristics of the pointed cones with half-angles of solution/opening of θ=30°, 45° and 60° at the fixed value of number $Re^{T}_{0D} = 65$, basis/base calculated according to the diameter, are given in Fig. 13-15.

At large angles of attack the aerodynamic characteristics of the pointed cones with half-angles of solution/opening of θ=15°, 20° and 30° at the fixed value of number $Re^{T}_{0D} = 97$ are given in Fig. 16-19.

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The effect of the flat/plane blunting whose relative size/dimension $\bar{d}=d/D$, where d and D - respectively the diameters of blunting and basis/base of cone, to the aerodynamic characteristics of slender cones with different half-angles of solution/opening at the fixed value of number Re^{T}_{0L} =162 for θ=2°.5 and 3°.75;

$Re_{0L}^{T} = 154$ for θ=6° and $Re_{0L}^{T} = 92$ for θ=10° is illustrated in Fig. 20-35.

For the low angles of attack, i.e., when the dependences of aerodynamic coefficients on the angle of attack are linear, given higher experimental data, which correspond to number $Re_{0L}^{T} = 162$, are represented in Fig. 36-38 in the form of dependences c_{x0}, c_{y0}^{α} and m_{z0}^{α} on the half-apex angle of the cone θ at different values of $\bar{d}$ of flat/plane blunting (c_{x0}, c_{y0}^{α}, m_{z0}^{α} - corresponding values c_x, $dc_y/d\alpha$, $dm_z/d\alpha$ with α=0). At the fixed value of number Re_{0L}^{T} the aerodynamic characteristics of cone in proportion to decrease θ considerably exceed the values, valid under the conditions for inviscid ideal flow. The effect of a small blunting of cone on its aerodynamic characteristics under the same conditions is unessential, at least in comparison with the analogous effect during the ideal flow.

The effect of spherical blunting on the aerodynamic characteristics of cone over a wide range changes in the parameters θ and $\bar{d}$ are given in Fig. 39-70. Criterion of similarity Re_{0D}^{T} for each θ was here by constant, its values were given below:

θ	3°,5	5°	7°,5	10°	12°,5	15°	17°,5	20°
Re_{0D}^{T}	20	29	43	57	72	87	102	118

Cylinder. The aerodynamic characteristics of cylinders (θ=0) at different values of L/D, where L and D - length and the diameter of cylinder, are given in Fig. 71-78. As the characteristic area S is

selected the area of basis/base, as the significant dimension of L - length of cylinder. At the fixed/recorded length of cylinder ($Re_{0L}=162$) the experimental data are given in Fig. 71-74, with fixed/recorded diameter ($Re^{T}_{0D}=13$) - in Fig. 75-78.

Body of revolution with the generatrix Re~$x^{3/4}$. The aerodynamic characteristics of the bodies of revolution, which have the equation of generatrix in the form of exponential monomial with the exponent of 3/4, are given in Fig. 79-82 at the different values of the relative thickness D/L, where D and L - diameter of basis/base and the length of body. As the characteristic area is accepted the area of basis/base S, as the significant dimension - length of body of revolution L. Criterion Re^{T}_{0L}, designed along the length of model, for each value of D/L is given below:

D/L	0,115	0,16	0,32	0,80
Re^{T}_{0L}	228	162	162	98

For the comparison in Fig. 79 and 80 dotted lines plotted/applied the drag coefficients and lift of acute cone at the same values of D/L and Re^{T}_{0L}.

Sphere. Resistance of sphere was studied both theoretically and by experimentally many authors. Basic experimental data are obtained in works [4, 17, 18] and are given in Fig. 7. The values of the drag coefficient $\bar{c}_x$ of sphere with the needle of variable of length, pertaining to drag coefficient of the sphere, in hypersonic flow of

rarefied gas are given in Fig. 83. On the same figure for the comparison are cited analogous data, obtained in work [26] with the large Re numbers. It is evident that with the small Re numbers a change in the length of needle weakly affects resistance of sphere.

Page 12.

Plate. Are given below the dependences of the aerodynamic characteristics of plate on its geometric parameters. As the characteristic area is accepted the area of plate S in the plan/layout, as the significant dimension - chord length in the root section L.

In the case of rectangular plate the effect of its relative thickness $\bar{\delta}_L=\delta L$ at several fixed values of the elongation of a plate λ and number $Re_{0L}^{\bar{}}$, designed along the length L, are illustrated Fig. 84-95, and the effect of the elongation of plate λ at constant values $\bar{\delta}_L$ and $Re_{0L}^{\bar{}}$ - Fig. 96-104. Fig. 105-107 presents dependences c_x, c_y and K on the angle of attack α for the rectangular plates with constant values of S and $\bar{\delta}_l=\delta/l=0{,}028$, where $l=\sqrt{S}$, over a wide range of change λ. Number $Re_{0l}^{\bar{}}$ here was calculated from the reference length l and was equal to 39.

The effect of sweep angle χ on the aerodynamic characteristics

of triangular plate at different values Re_{0L}^{T} and $\bar{\delta}_L$ is shown in Fig. 108-115. The values of the aerodynamic characteristics of triangular plates over a wide range of change λ at constant values of S and $\bar{\delta}_l=\delta l=0{,}028$, where $l=\sqrt{S}$, are given in Fig. 116-119. Number Re_{0l}^{T} here again was calculated from the reference length l and was equal to 39.

As it follows from given experimental data, viscosity effect significantly changes the character of the flow around body, as a result of which the dependence of the aerodynamic characteristics of bodies on their geometric parameters becomes different from that which is observed with the large Reynolds numbers. For example, the given in works [19, 20] results of the systematic studies of the aerodynamic characteristics of the plates of the fixed/recorded area showed that with a change in the elongation λ the dependence of maximum lift-drag ratio K_{max}, has a maximum at the finite value λ. The results of these investigations are given in Fig. 120-123 in the form of the dependences of maximum lift-drag ratio K_{max} and angle of attack α_{max}, which corresponds K_{max} on the elongation λ and relative thickness $\bar{\delta}_l$ for the plates of different planform. As it follows from given data, in the hypersonic low-density flow the wings with the elongations λ=0.4-0.8 have advantages from the point of view of lift effectiveness in comparison with the wings of other elongations, moreover with the sufficiently small wing chord ratio $\bar{\delta}_l \leqslant 0{,}03$ independent of its form optimum is wing with the elongation λ=0.6.

The aerodynamic coefficients of the plates of various forms and fixed/recorded area S, streamlined at the high angles of attack ($\alpha \approx 90°$), are represented in Table 1.

Table 1.

(1) Коэффициенты	(2) Форма пластин						
	(3) Окружность	(4) Эллипс	(5) Ромб	(6) Прямоугольник			(7) Равносторонний треугольник
λ	1	0,496	0,509	1	0,491	0,317	1,155
$\bar{\delta}_l$	0,2	0,2	0,2	0,25	0,19	0,18	0,195
c_{x0}	1,81	1,81	1,85	1,85	1,85	1,88	1,92
c_{y0}^{α}	0,0207	0,0220	0,0220	0,0195	0,0226	0,0255	0,0200

Key: (1). Coefficients. (2). Form of plates. (3). Circle/circumference. (4). Ellipse. (5). Rhomb. (6). Rectangle. (7). Equilateral triangle.

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Number Re_{0l}^{T} was calculated in this case over the reference length $l\sqrt{S}$ and was equal to 65. As with the large Re numbers [27] the form of flat/plane blunting virtually does not affect the value of aerodynamic coefficients.

Three-dimensional bodies. The aerodynamic characteristics of three-dimensional bodies are analyzed based on the examples of semicone and combination of wing with the semicone. As the characteristic area is accepted the area of model in plan/layout S, as the significant dimension - chord length in the root section L.

The effect of blind sectors of body on its aerodynamic characteristics was investigated based on the example of semicone. In the case when the conical part of the semicone is turned towards the flow, aerodynamic coefficients for the semicone are compared with the appropriate characteristics of complete cone. When $Re^{T}_{0L}=130$ corresponding data for the cone with a half-angle of solution/opening of θ=15° are cited in Fig. 124-127.

In the case when the flat surface of semicone is turned towards the flow, the aerodynamic characteristics of semicone with θ=15° with number $Re^{T}_{0L}=130$ are compared with the appropriate characteristics of triangular plate with the sweep angle of χ=75° ($\bar{\delta}_L=0{,}025$) in Fig. 128-131.

As follows from given data, in the mode/conditions hypersonic flows of rarefied gas the effect of blind sectors of body on its aerodynamic characteristics it becomes essential.

Fig. 132-139 gives the values of the aerodynamic characteristics of the model, which is the combination of the blunted semicone with the tapered wing. The sweep angle of wing of χ=75°, chord length in the root section is equal to the length of semicone L, and the length of leading edge - to diameter of the flat/plane blunting d of semicone. Number $Re^{T}_{0L}=130$, angles of attack α are considered positive, when the flat surface of model is turned towards the flow.

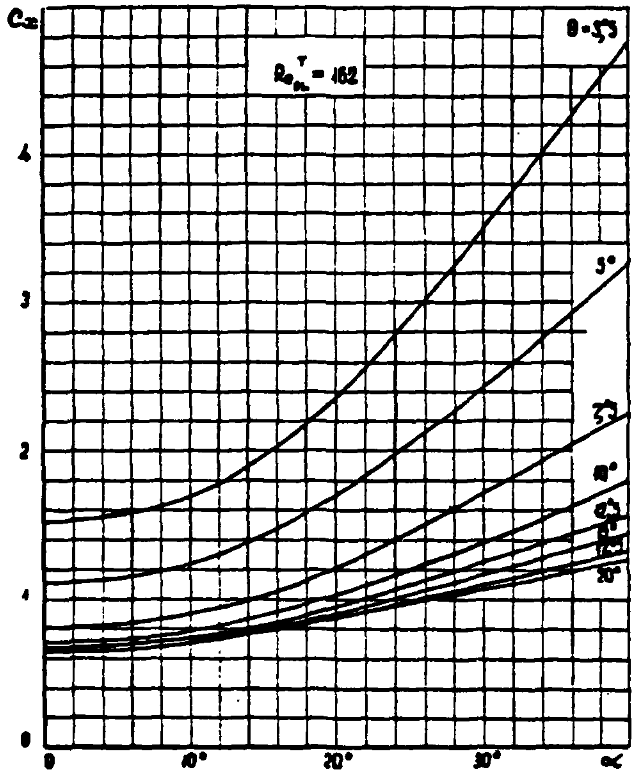

Fig. 9.

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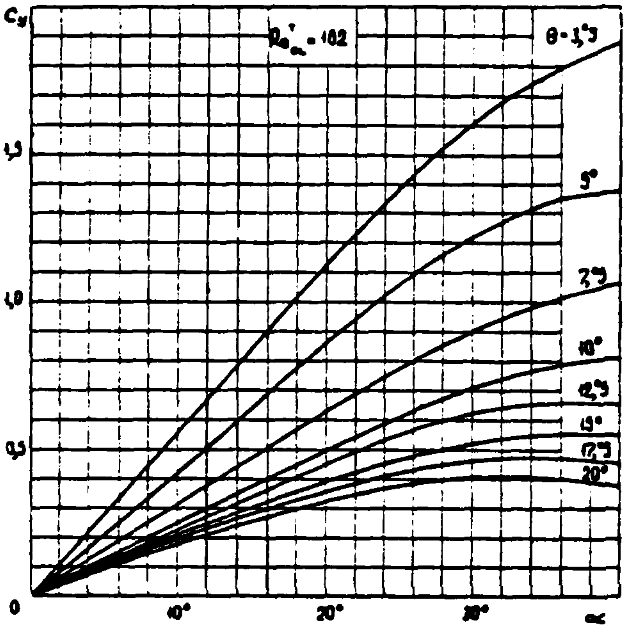

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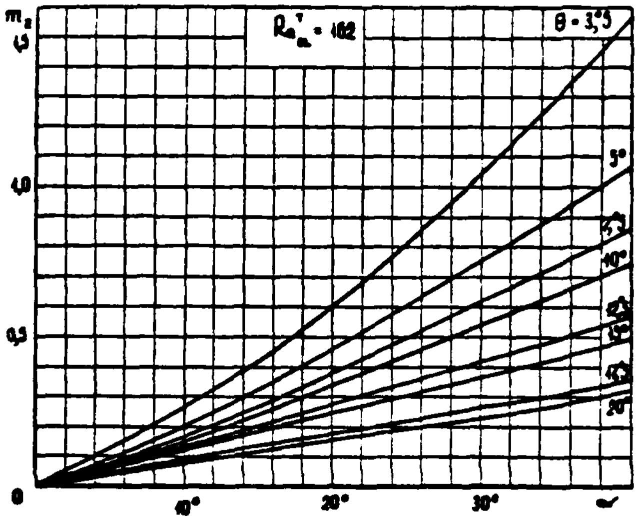

Fig. 11.

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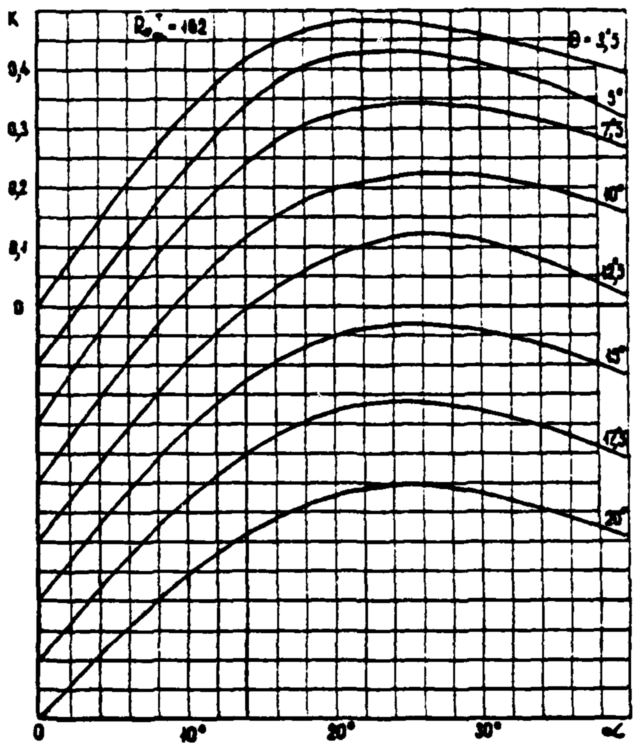

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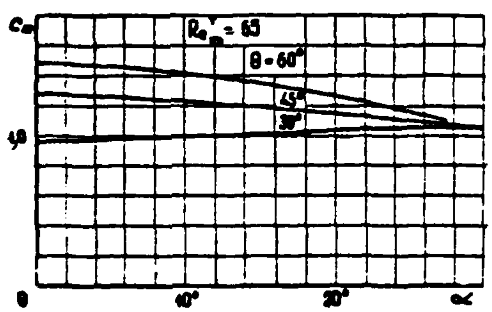

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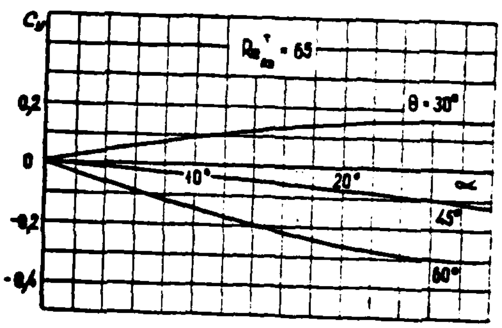

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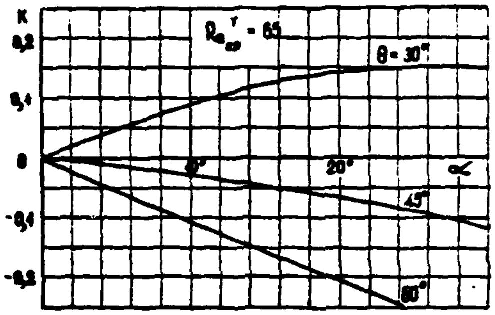

Fig. 15.

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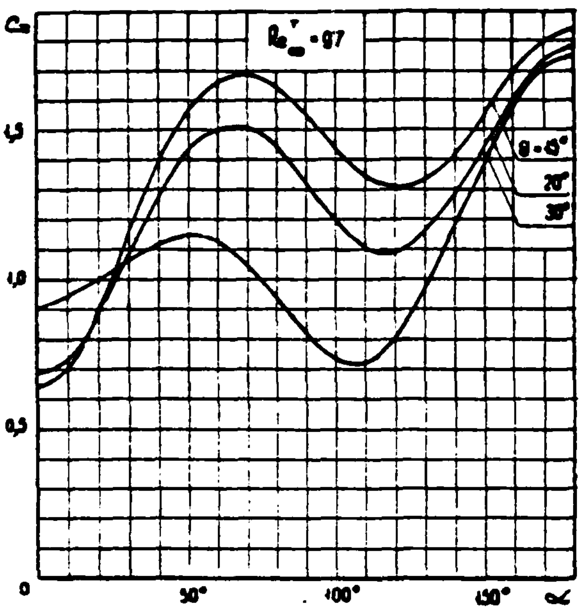

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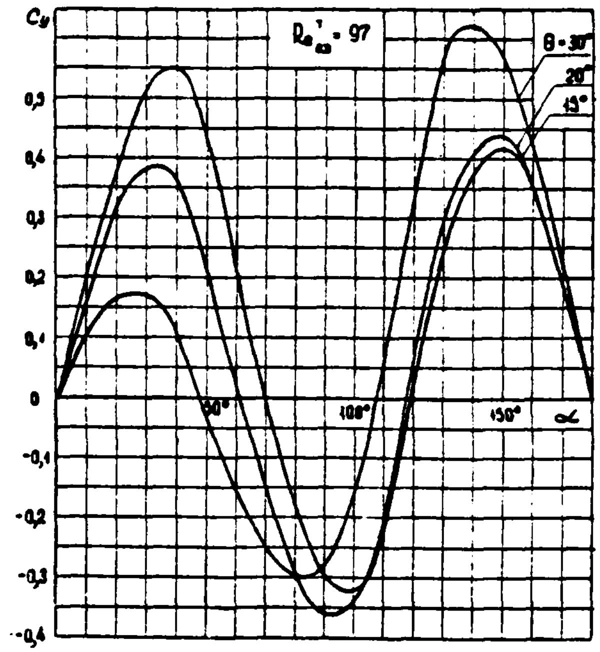

Fig. 17.

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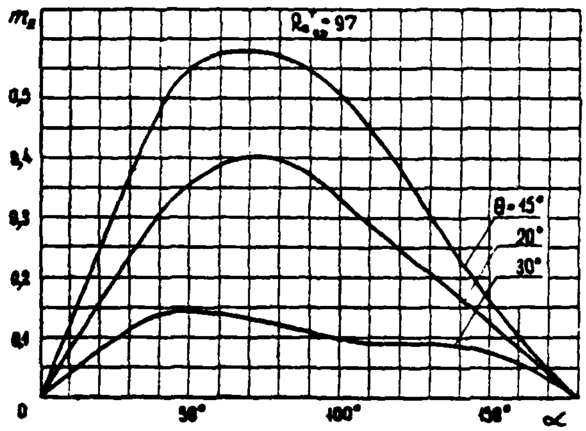

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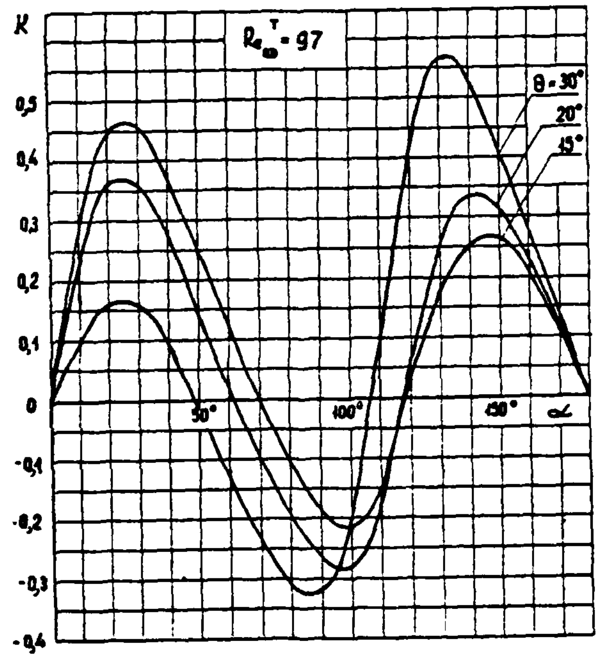

Fig. 19.

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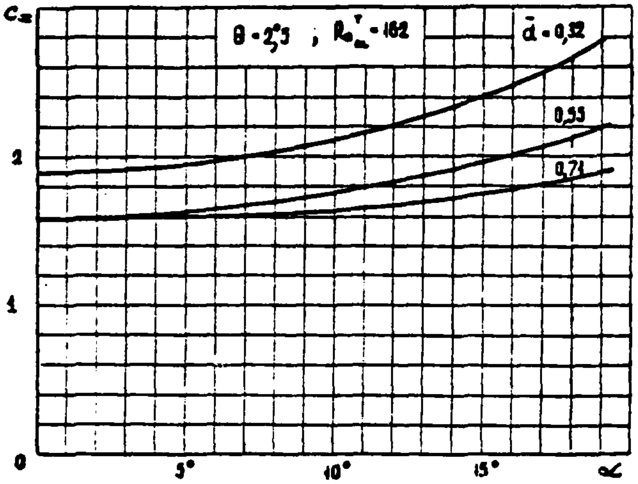
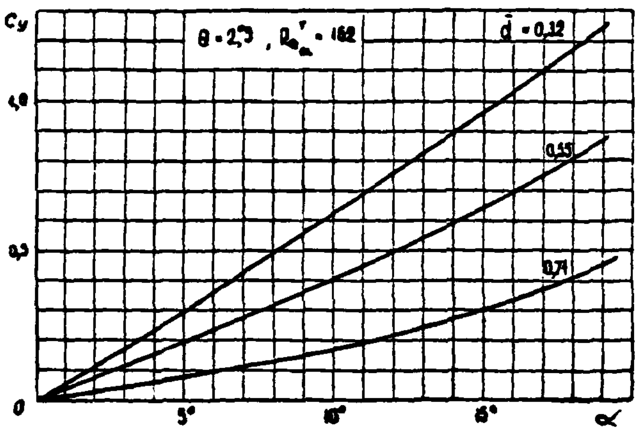
Fig. 20.





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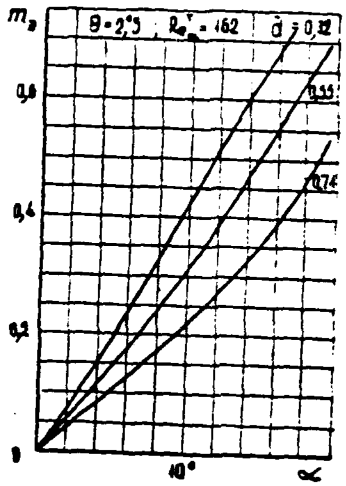

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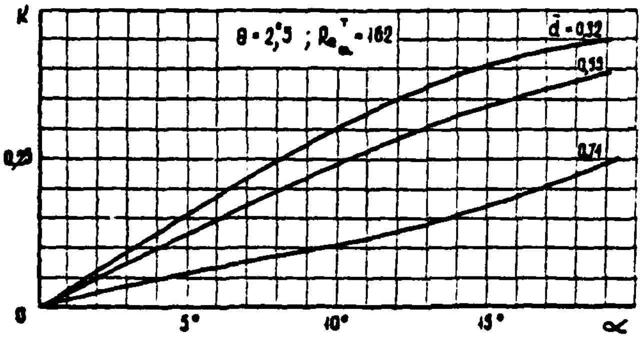

Fig. 23.

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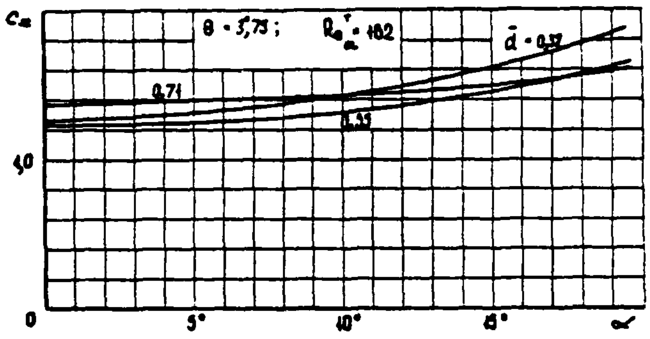

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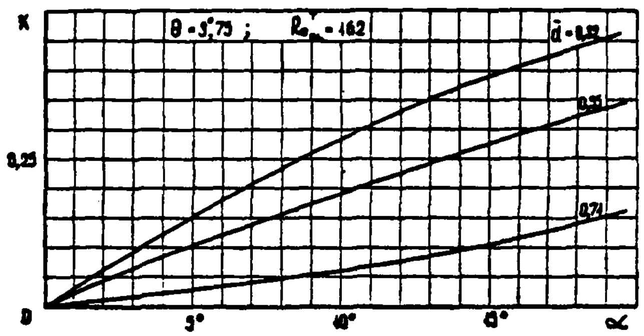

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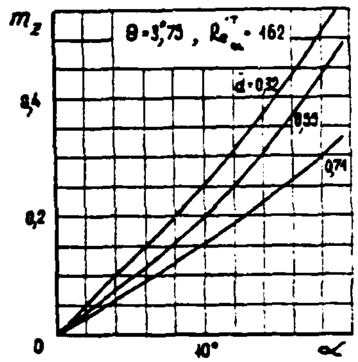

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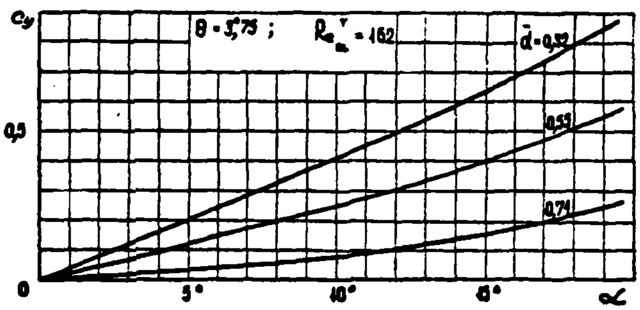

Fig. 27.

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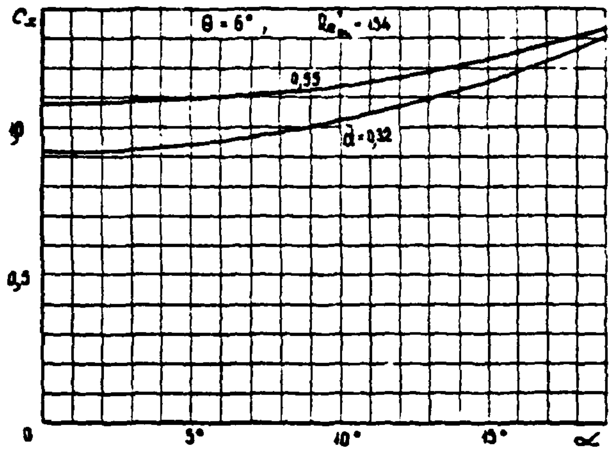

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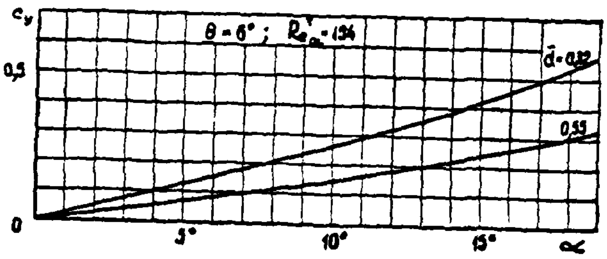

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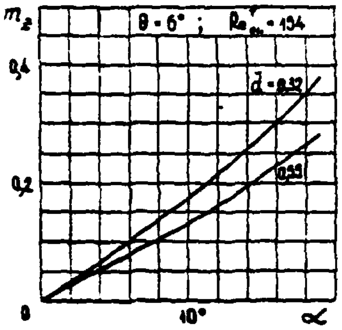

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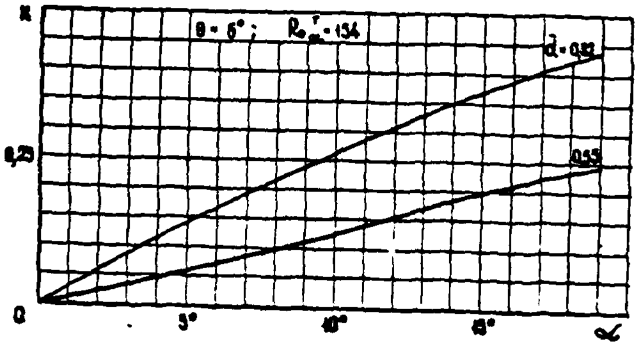

Fig. 31.

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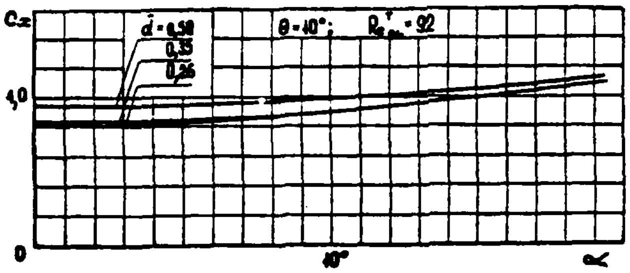

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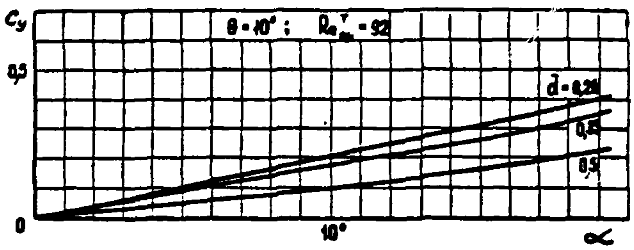

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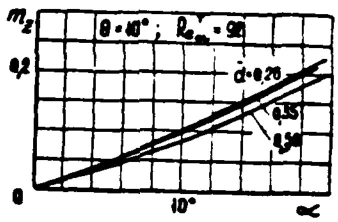

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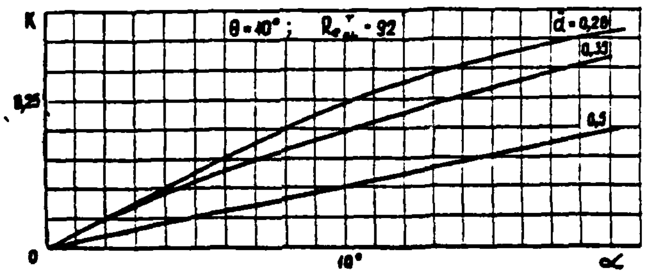

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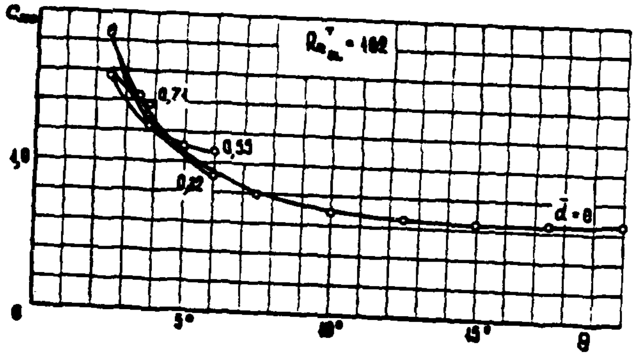

Fig. 36.

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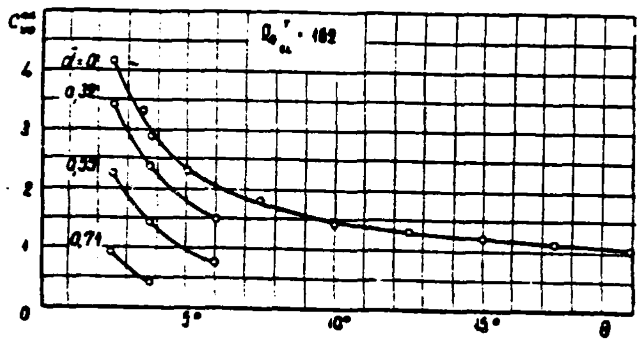

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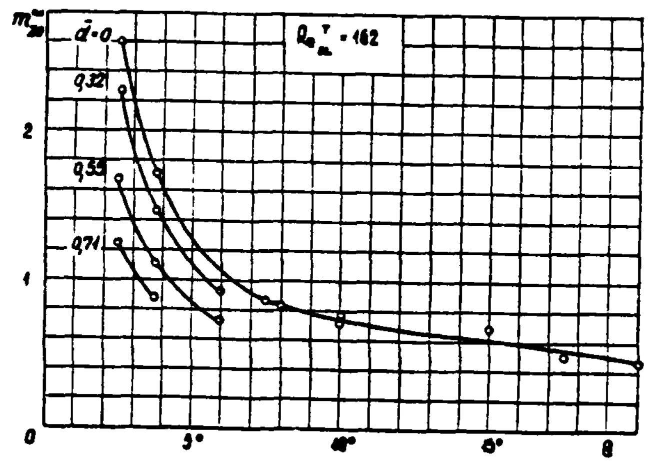

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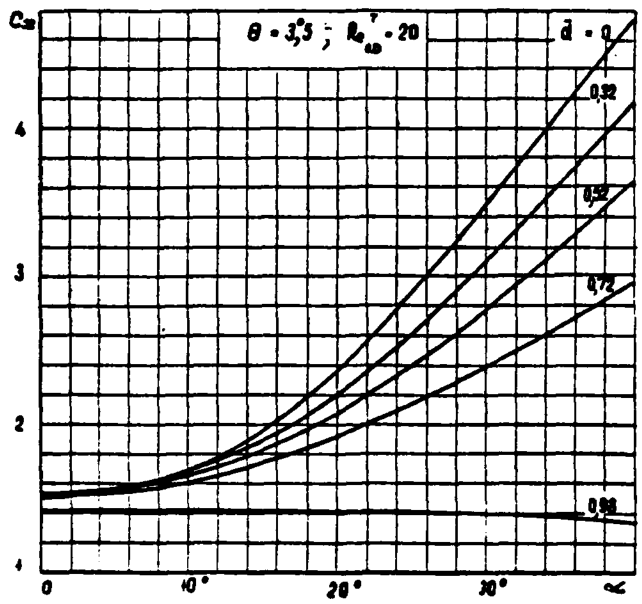

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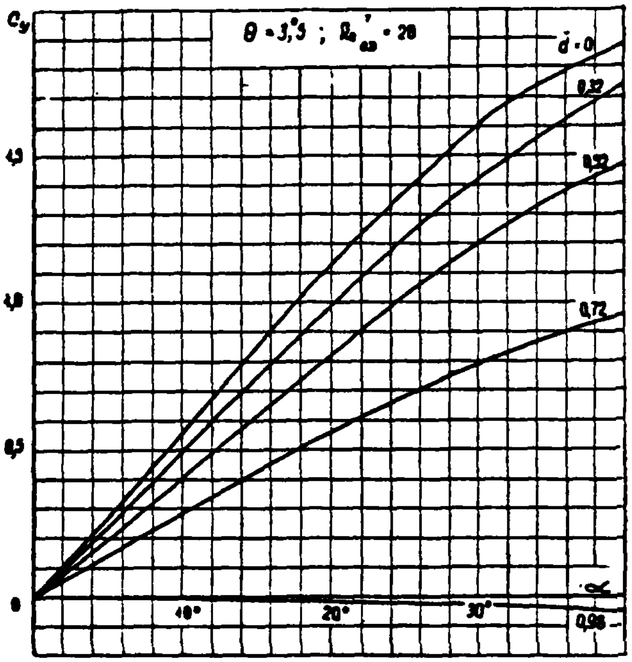

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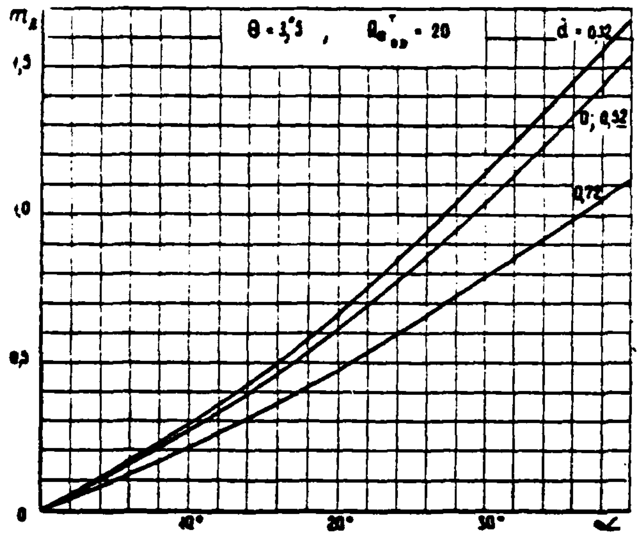

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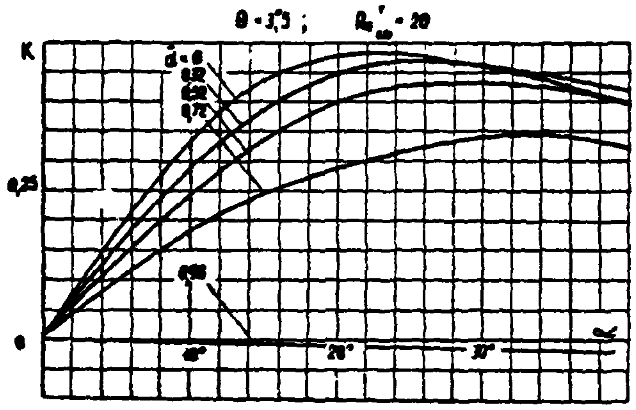

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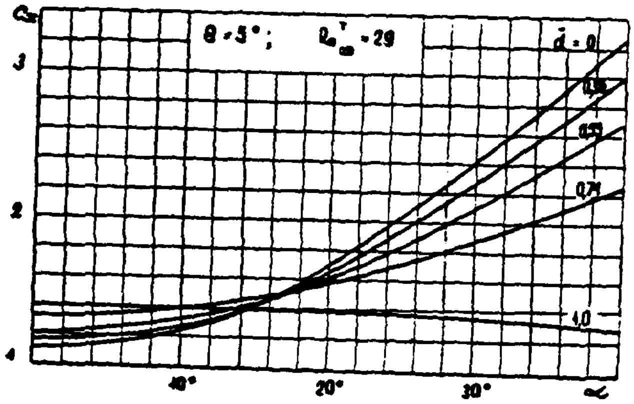

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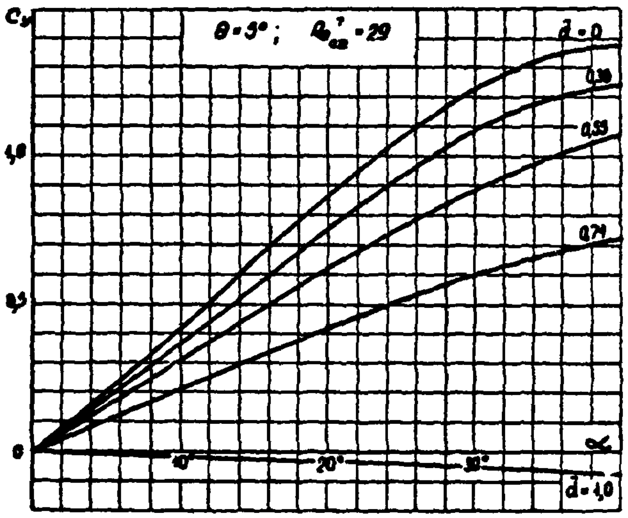

Fig. 44.

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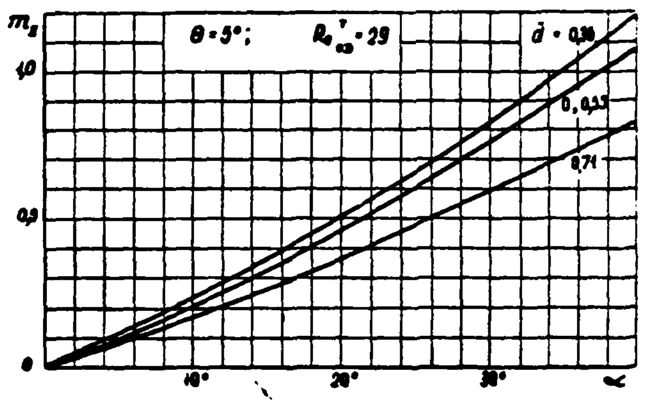

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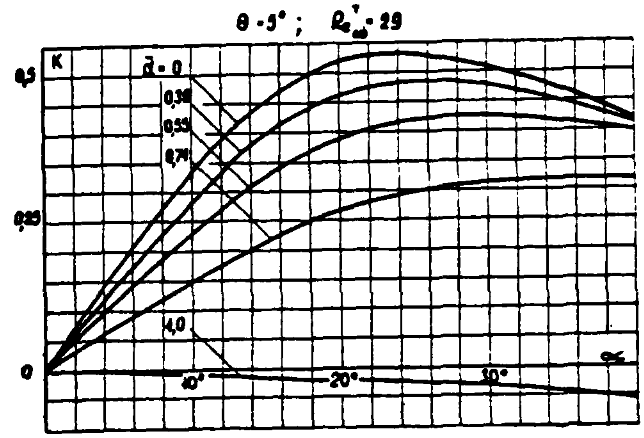

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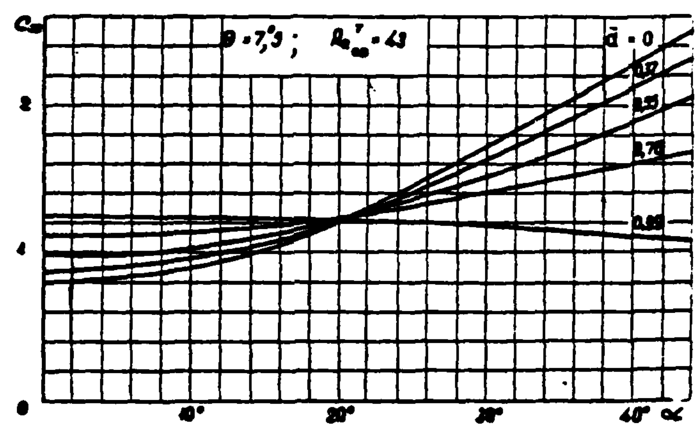

Fig. 47.

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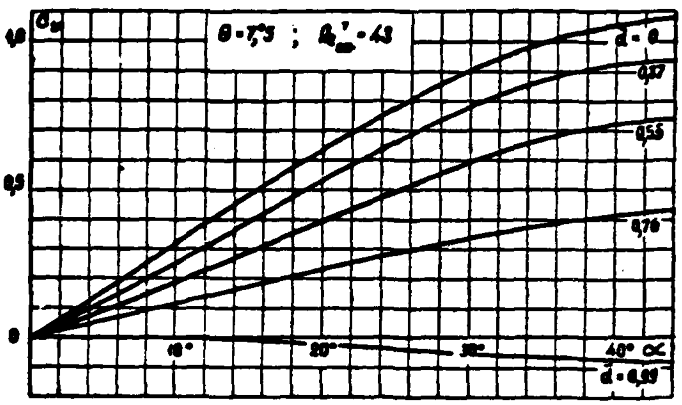

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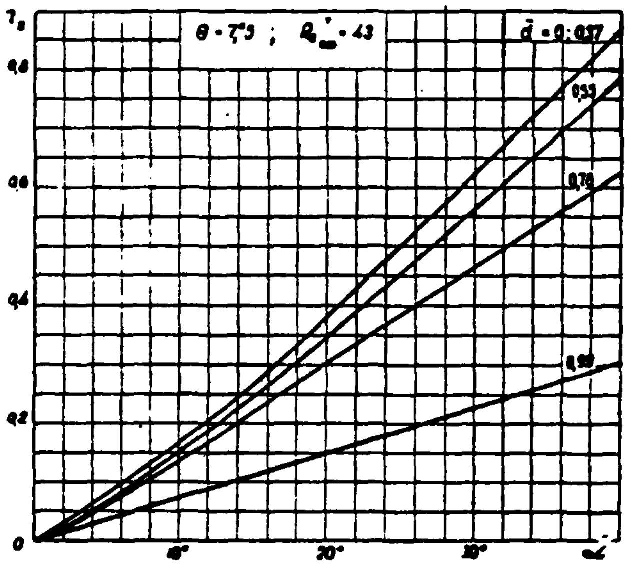

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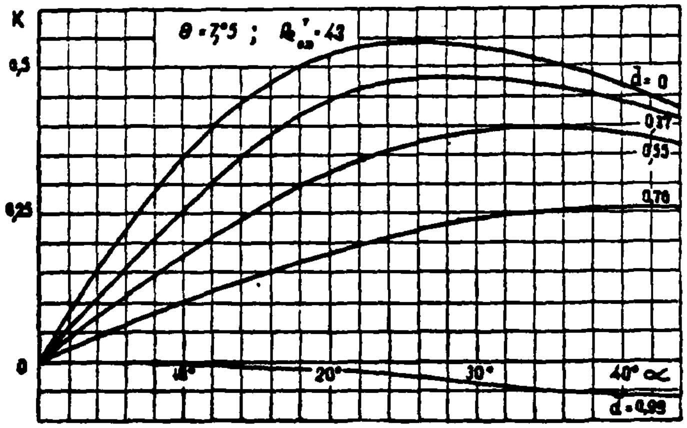

Fig. 50.

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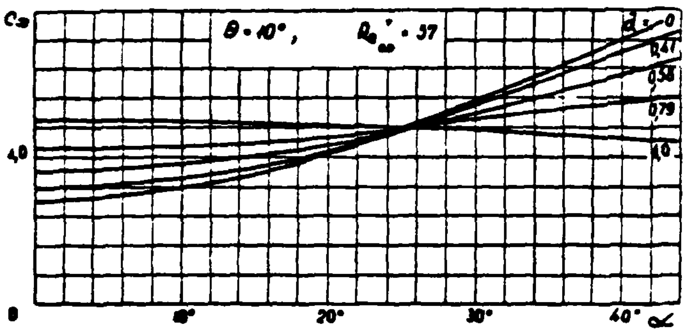

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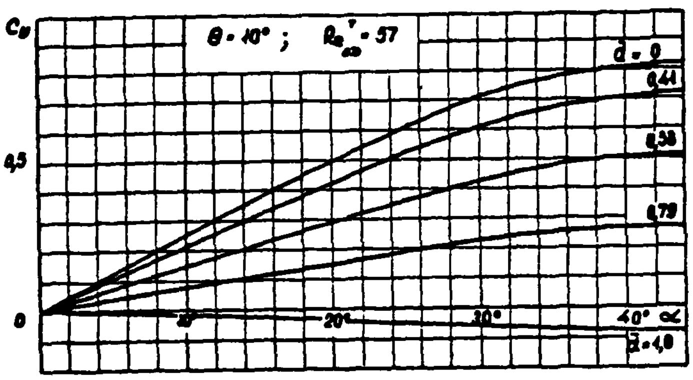

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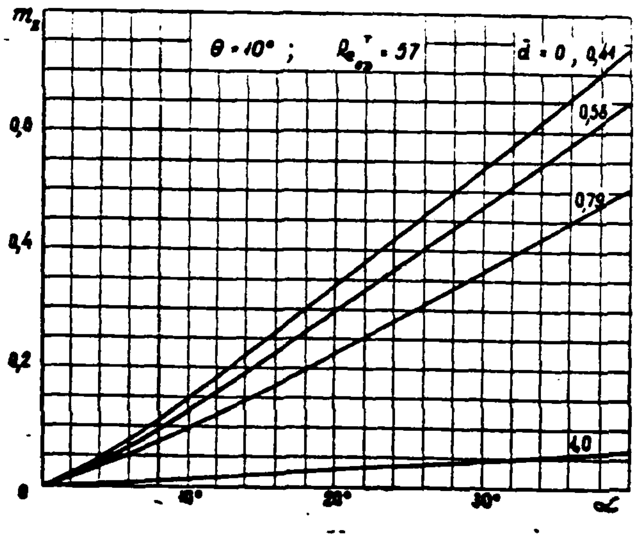
m_z
$\theta = 10°$; $Re_{cr}^{T} = 57$
$\bar{d} = 0$, 0,41
0,58
0,79
1,0
0,8
0,4
0,2
0
10°
20°
30°
α

Fig. 53.

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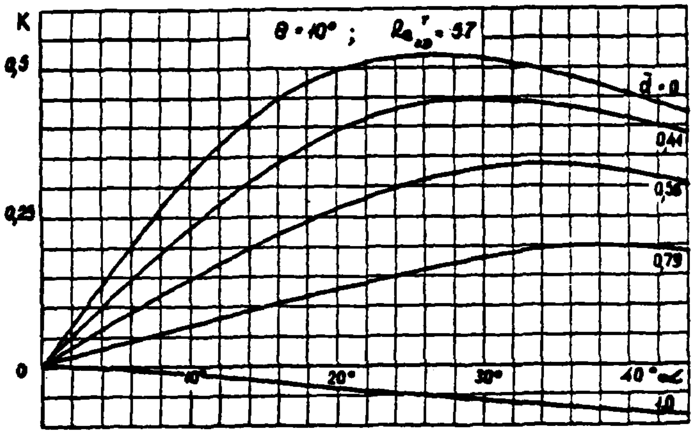

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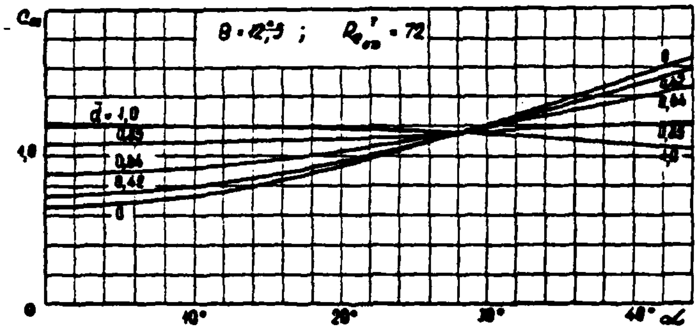

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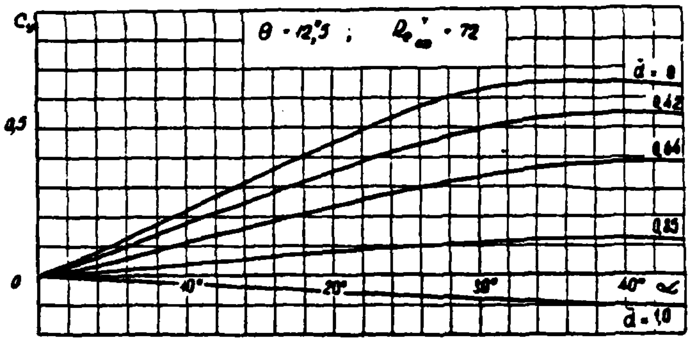

Fig. 56.

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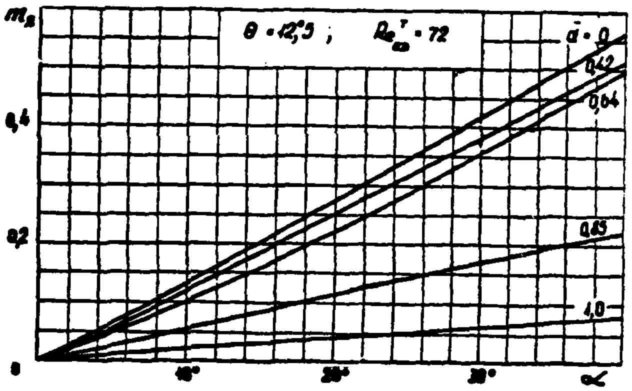

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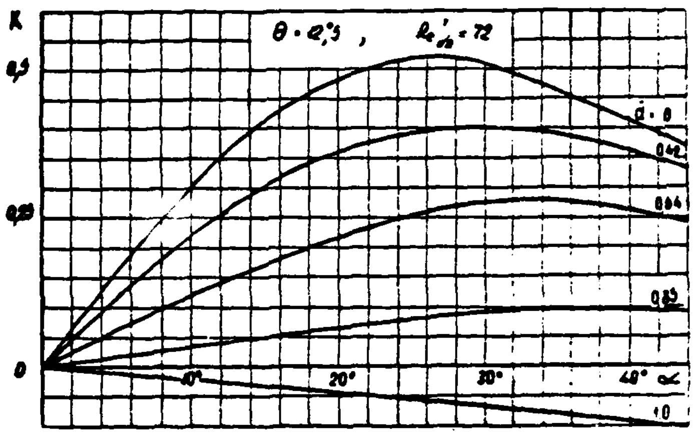

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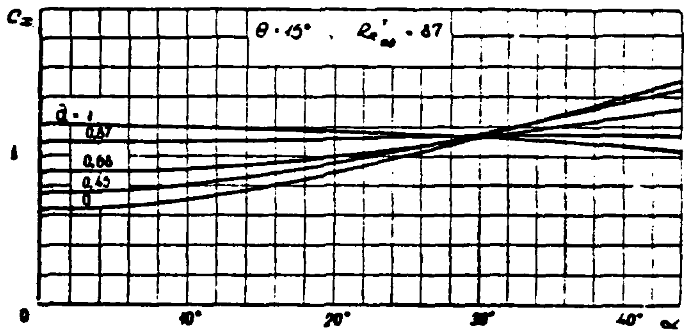

Fig. 59.

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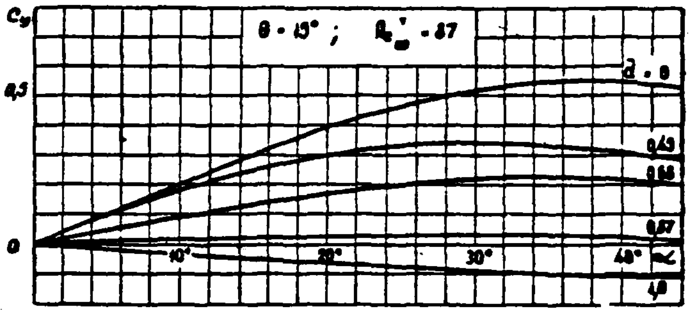

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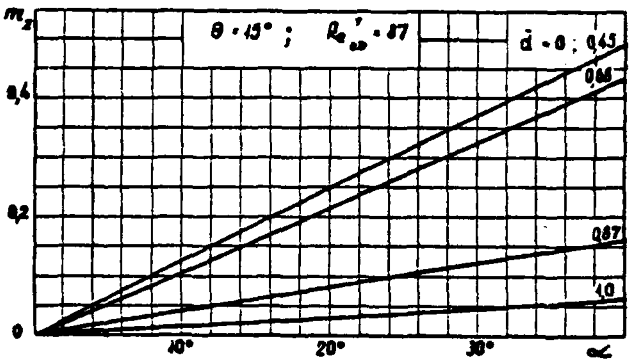

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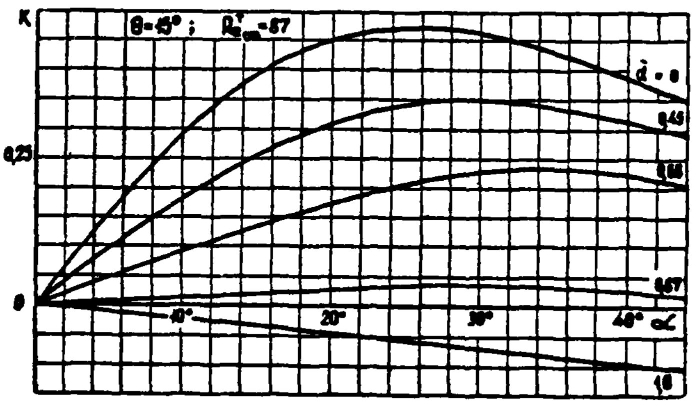

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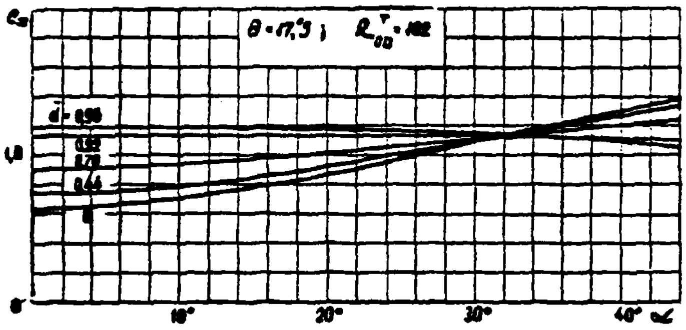

Fig. 63.

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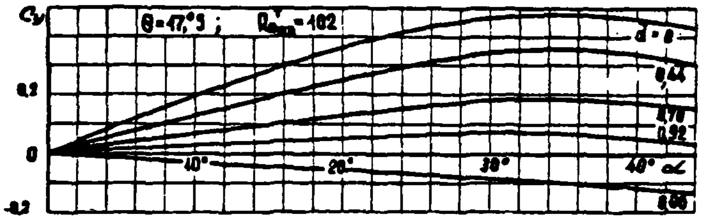

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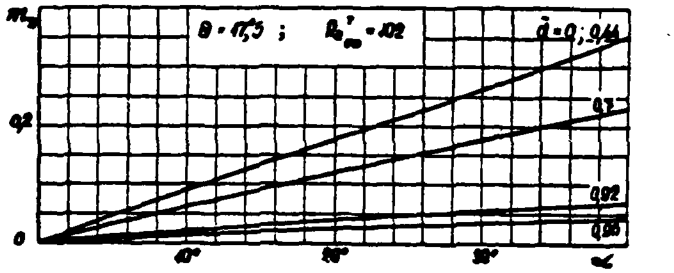

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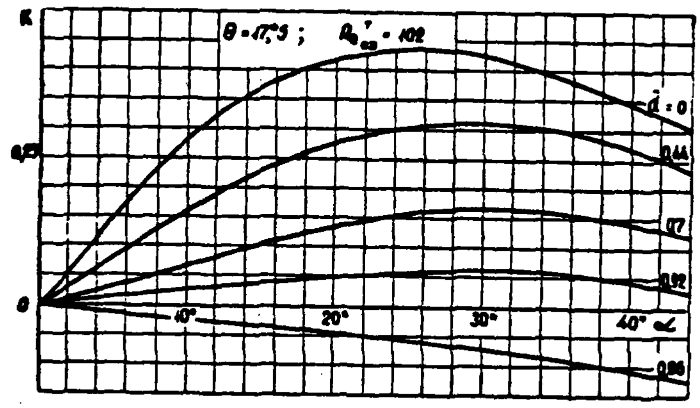

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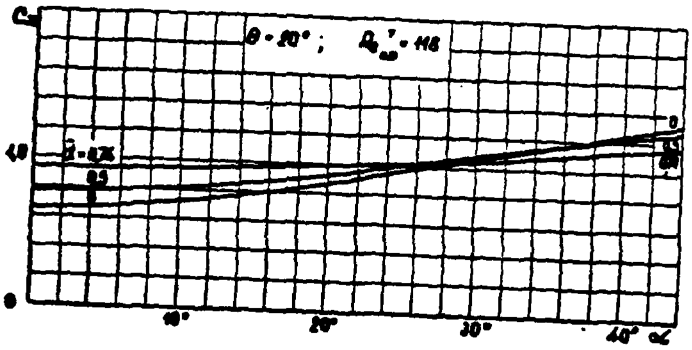

Fig. 67.

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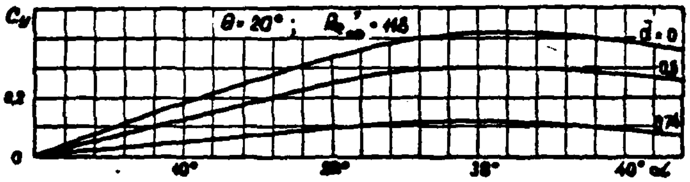

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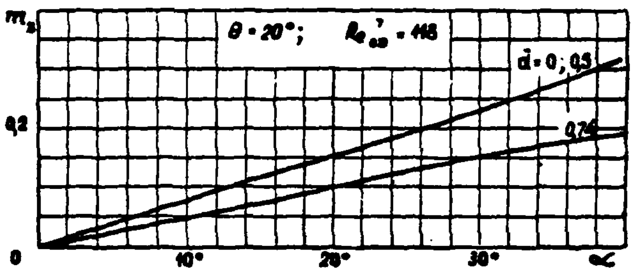

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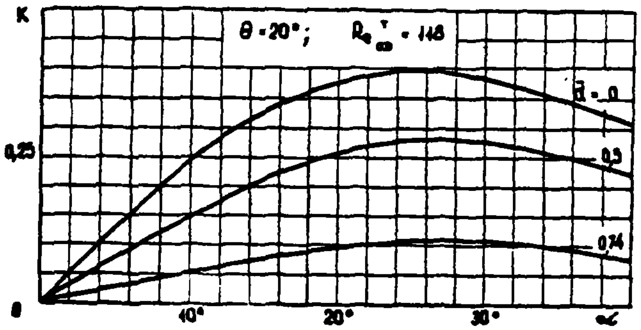

Fig. 70.

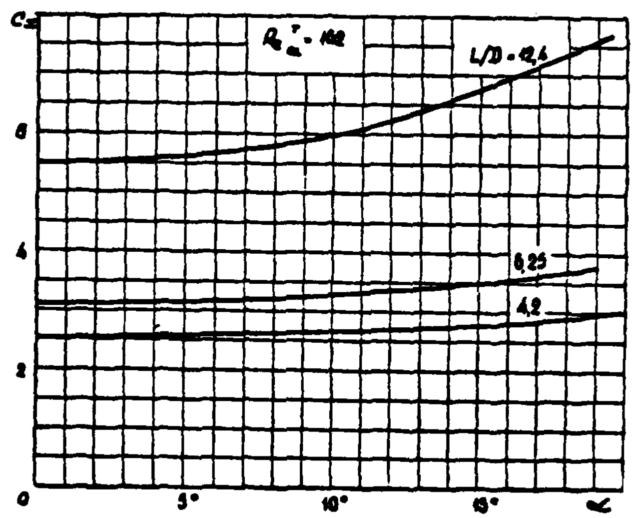

Fig. 71.

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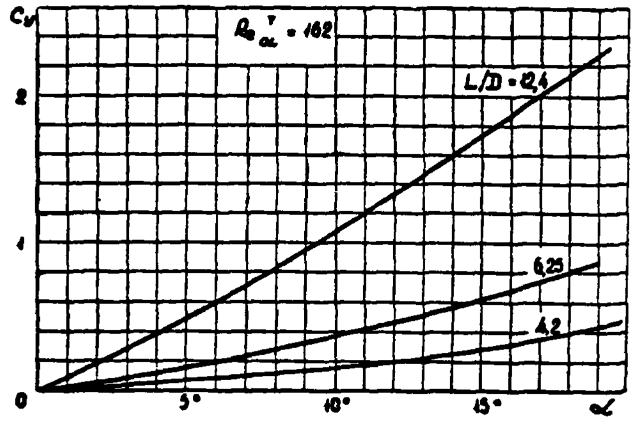

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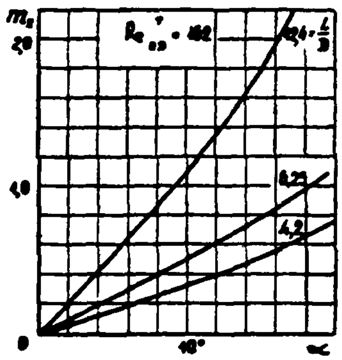
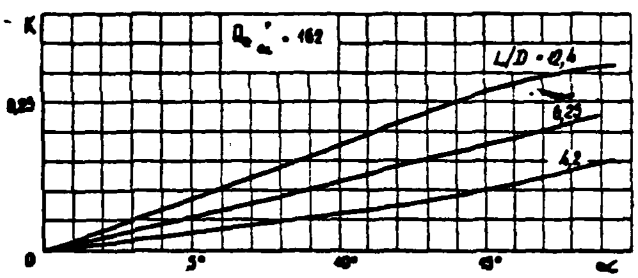


Fig. 73.



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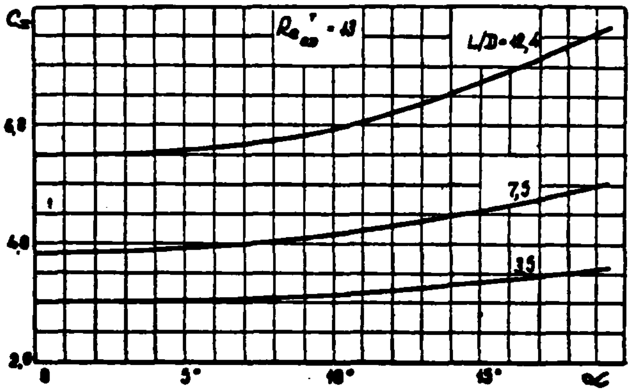
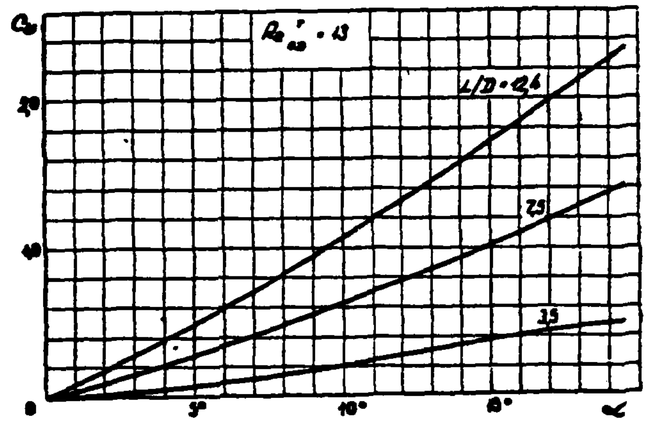


Fig. 75.

Page 34.



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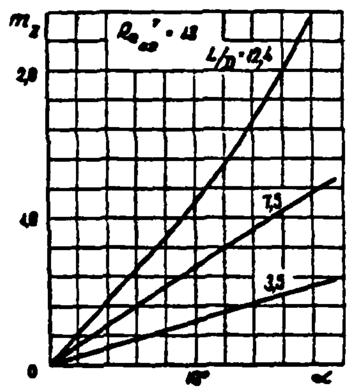

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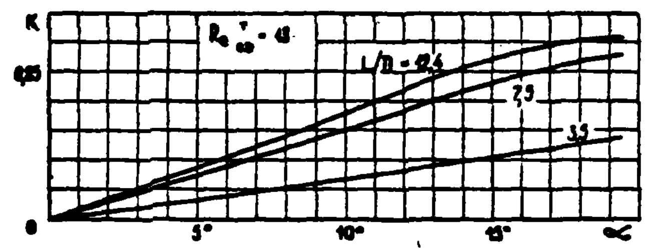

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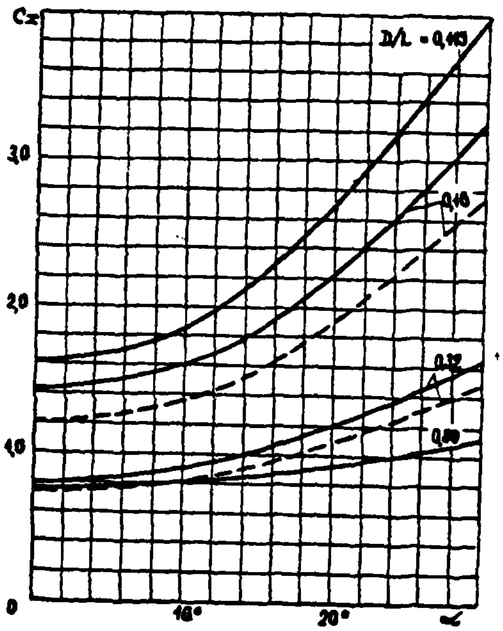
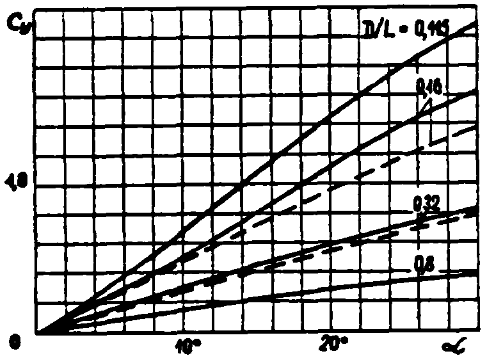


Fig. 79.

Page 35.



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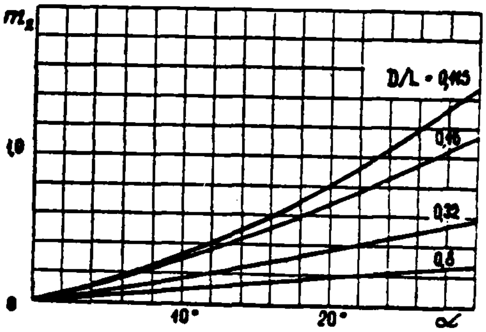

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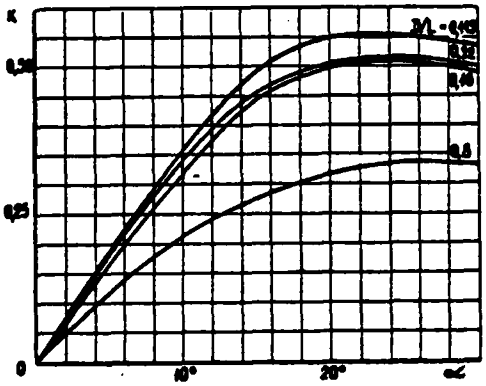

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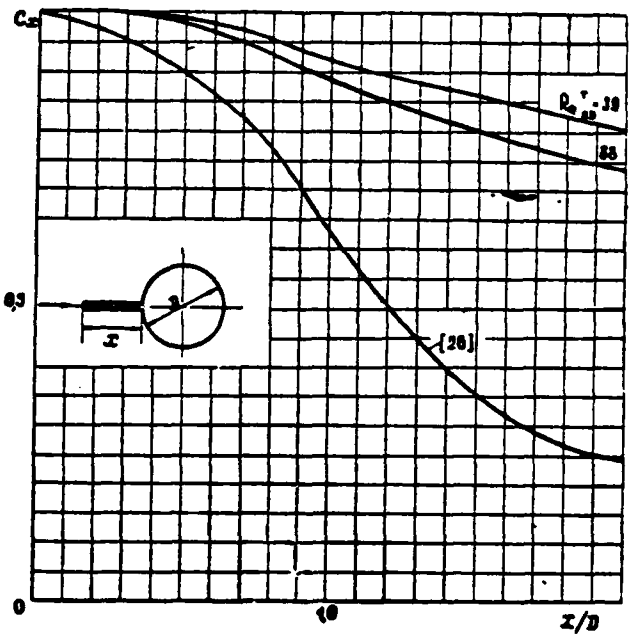
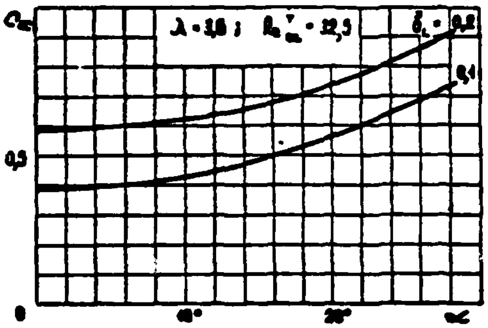


Fig. 83.

Page 36.



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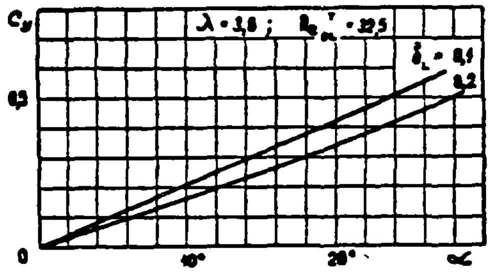

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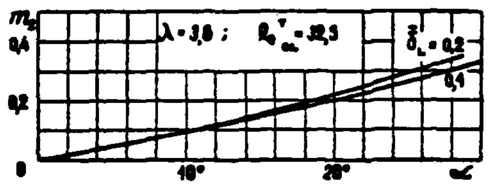

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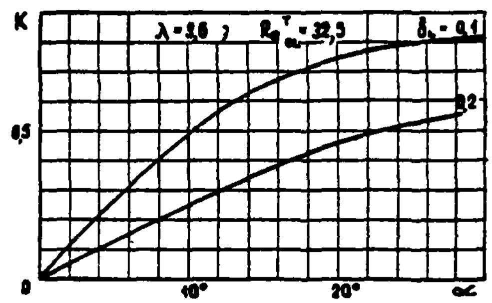

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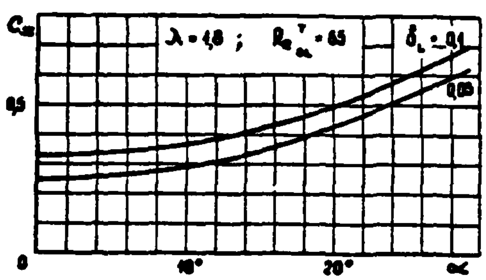

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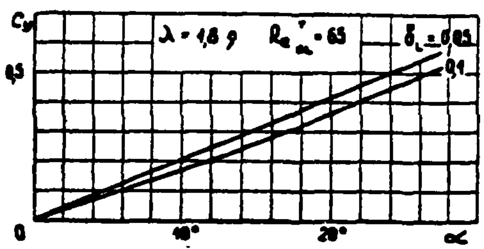

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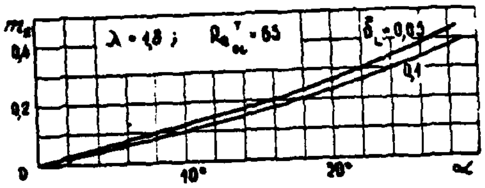

m_z
0,4
0,2
0
10°
20°
α
λ = 1,8 ; Re_{cr}^{T} = 65
$\bar{\delta}_c$ = 0,05
0,1

Fig. 90.

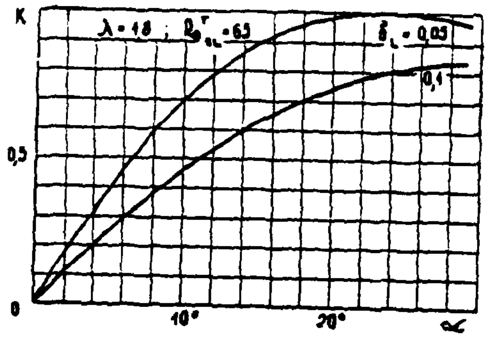
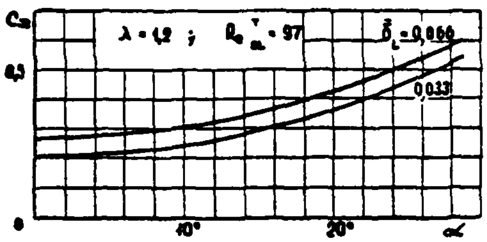

K
0,5
0
10°
20°
α
λ = 1,8 ; Re_{cr}^{T} = 65
$\bar{\delta}_c$ = 0,05
0,1

Fig. 91.

Page 37.



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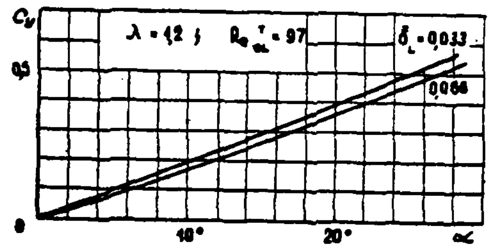


Fig. 93.

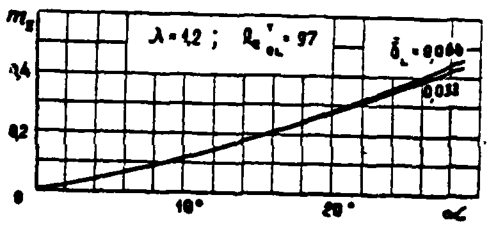
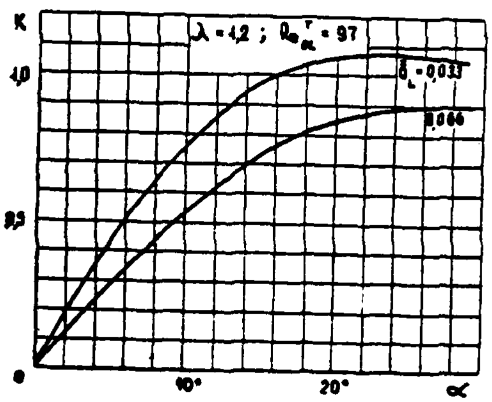


Fig. 94.



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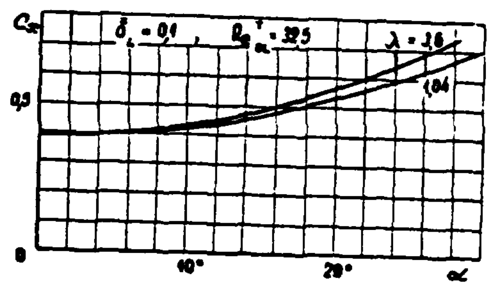


Fig. 96.

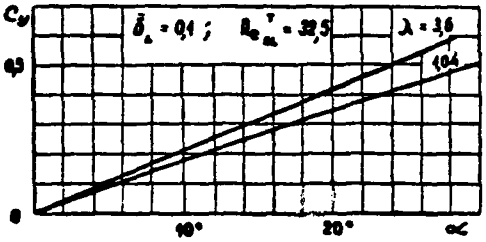

C_y
$\bar{\delta}_L = 0,1$; $Re_{\text{вл}}^{T} = 32,5$
$\lambda = 3,6$
10,4
0,5
0
10°
20°
α

Fig. 97.

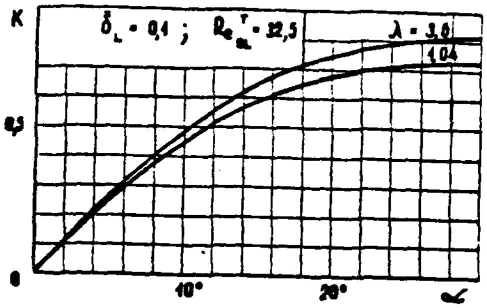
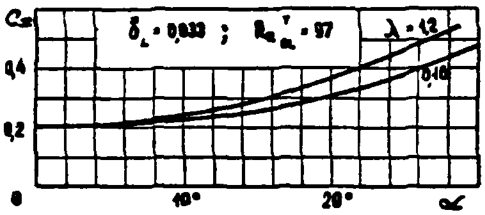

K
$\bar{\delta}_L = 0,1$; $Re_{\text{вл}}^{T} = 32,5$
$\lambda = 3,6$
10,4
0,5
0
10°
20°
α

Fig. 98.

Page 38.



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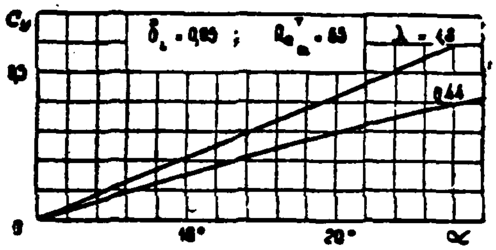

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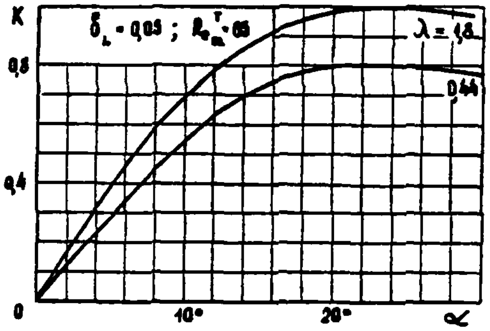

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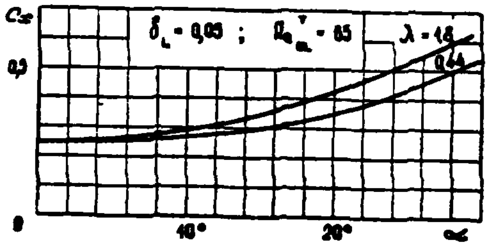

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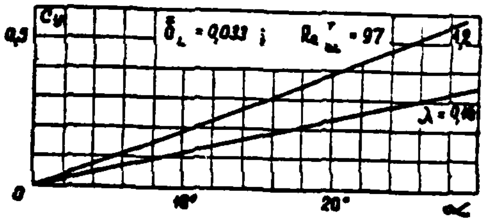

Fig. 103.

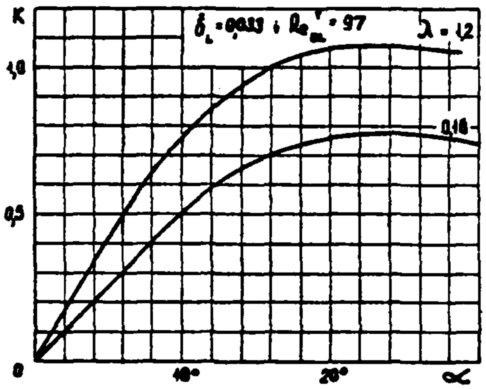

Fig. 104.

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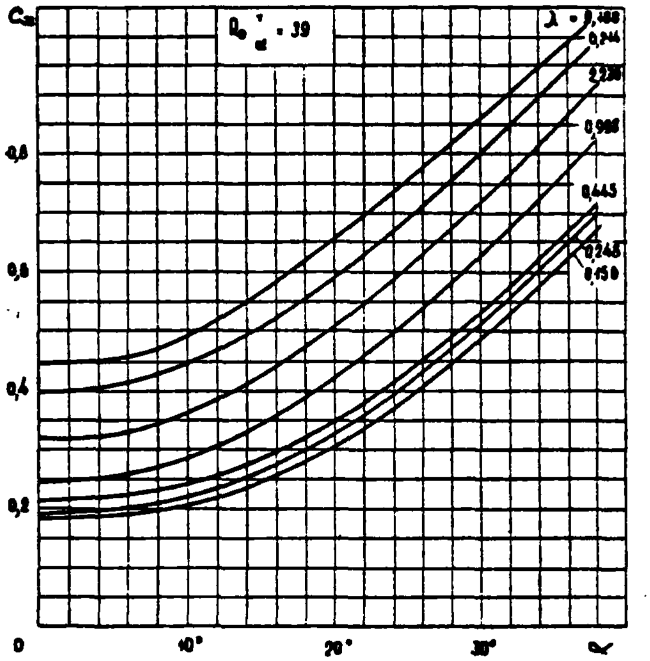

Fig. 105.

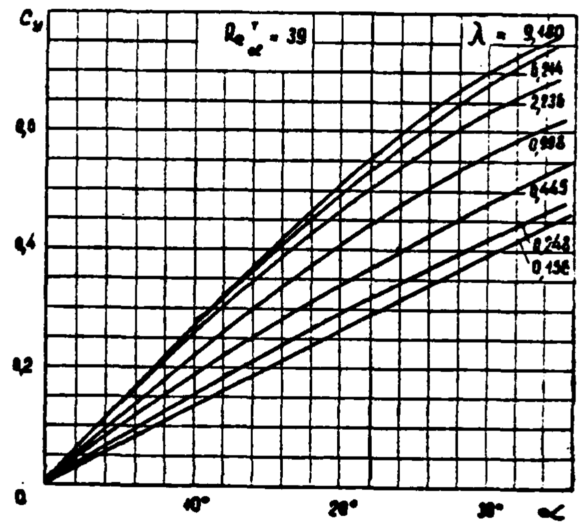

Fig. 106.

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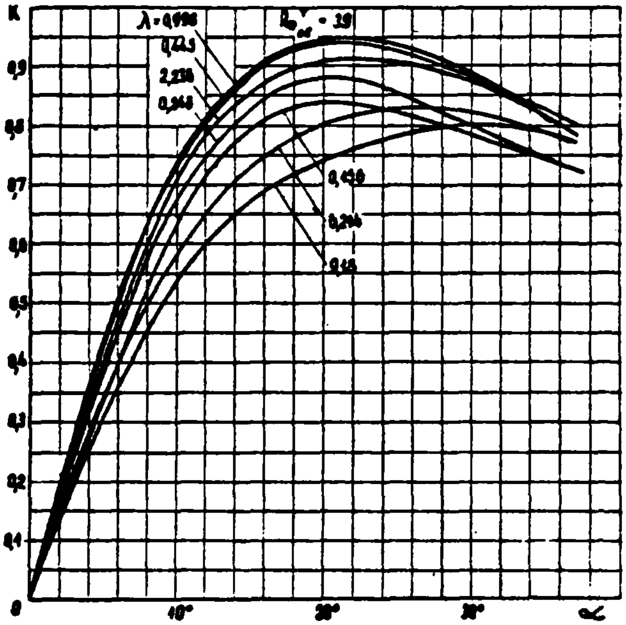

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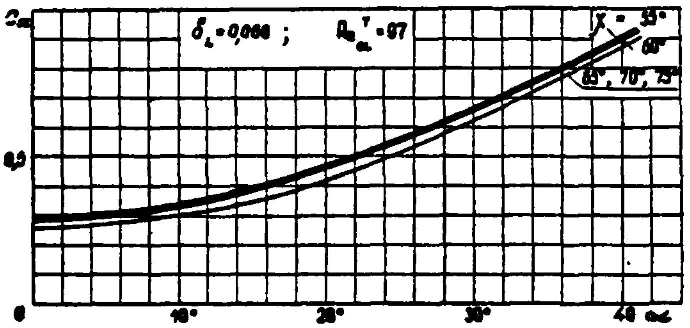

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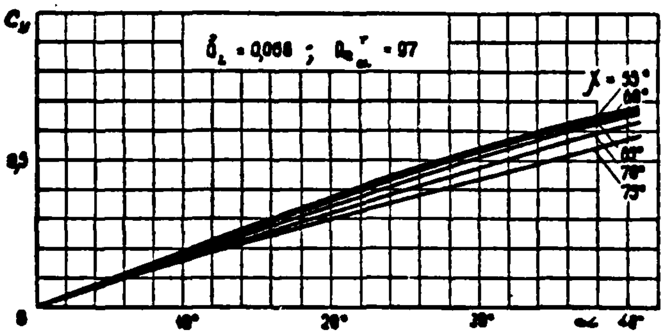

Fig. 109.

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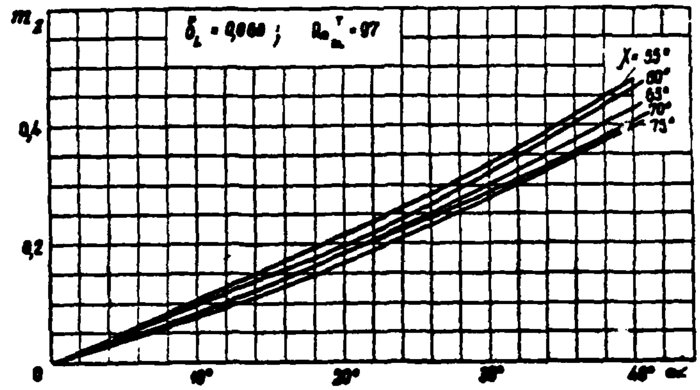

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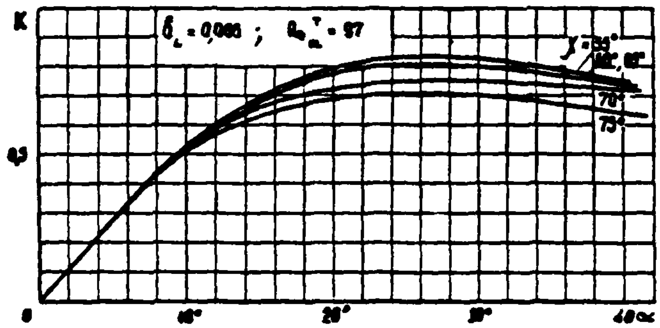

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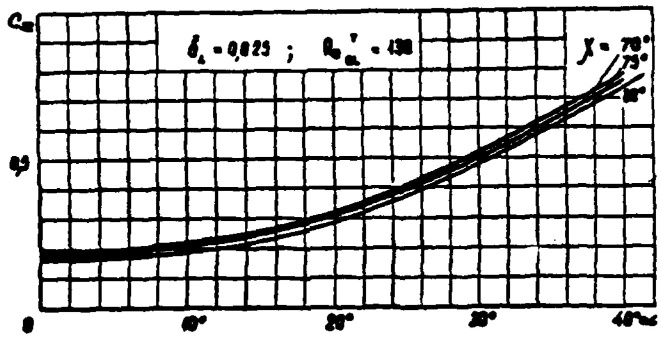

Fig. 112.

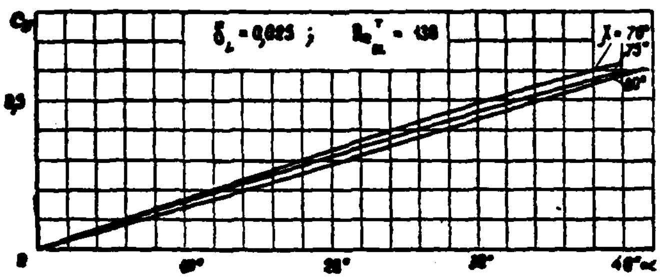

Fig. 113.

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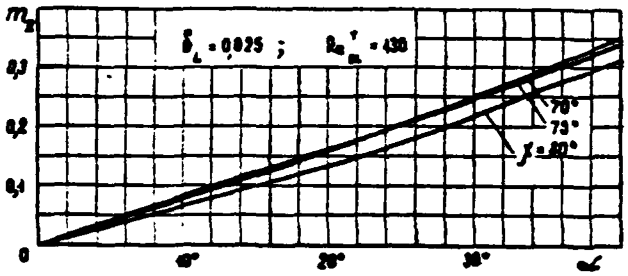
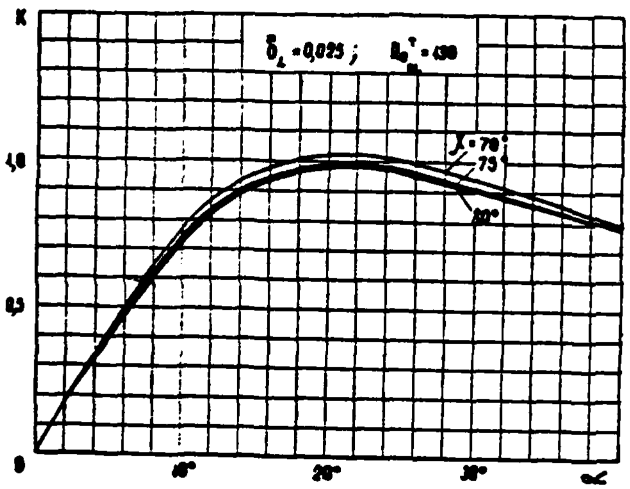


Fig. 114.



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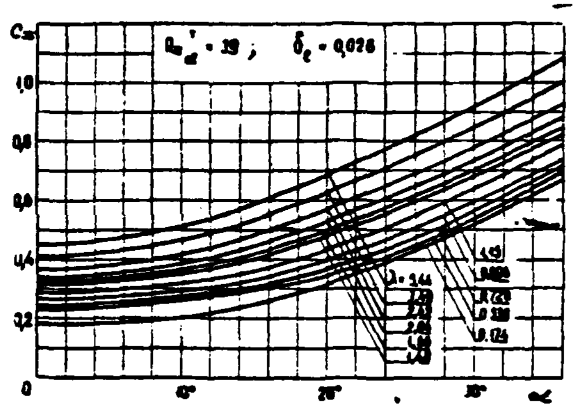

Fig. 116.

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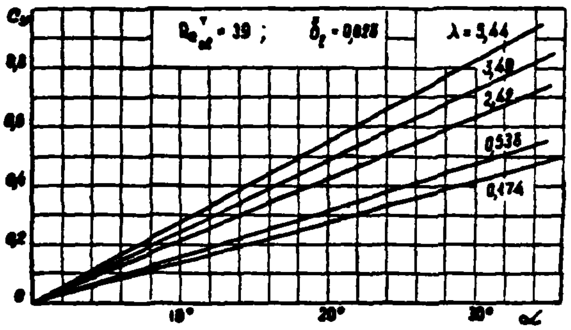
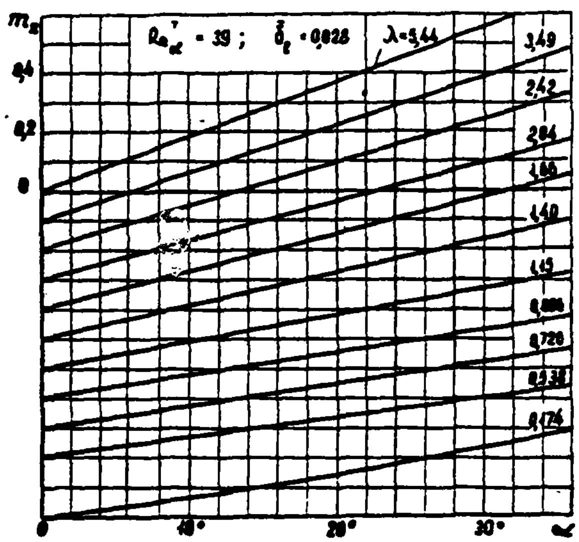


Fig. 117.



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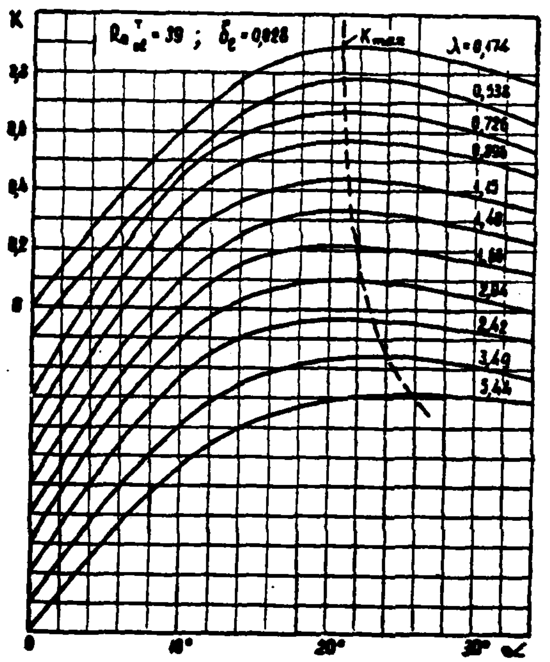

Fig. 119.

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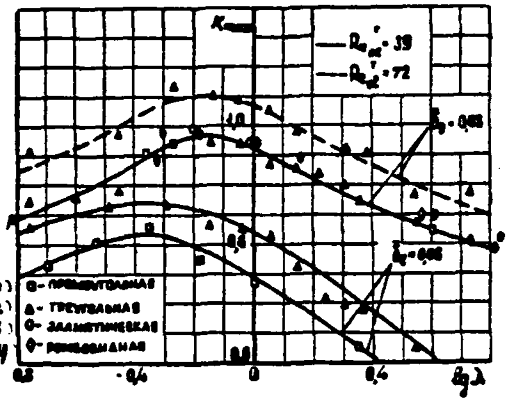

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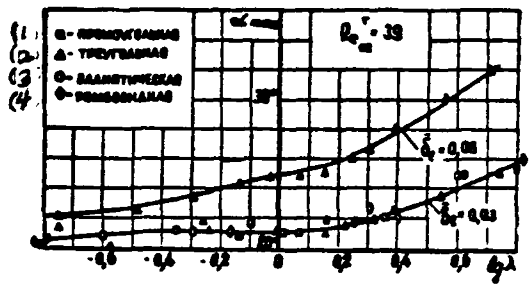
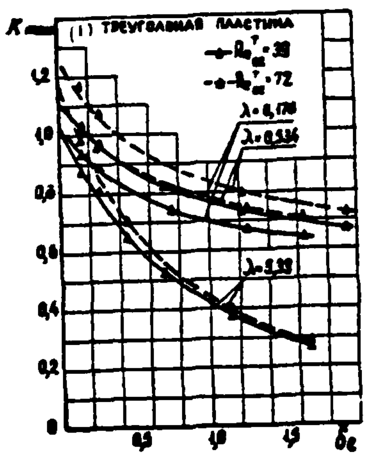


Fig. 121.

Fig. 120. Key: (1). rectangular. (2). triangular. (3). elliptical. (4). rhombiform.

Fig. 121. Key: (1). rectangular. (2). triangular. (3). elliptical. (4). rhombiform.



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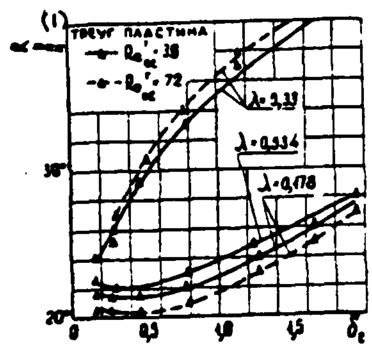

Fig. 123.

Fig. 122. Key: (1). triangular plate.

Fig. 123. Key: (1). triangular plate.

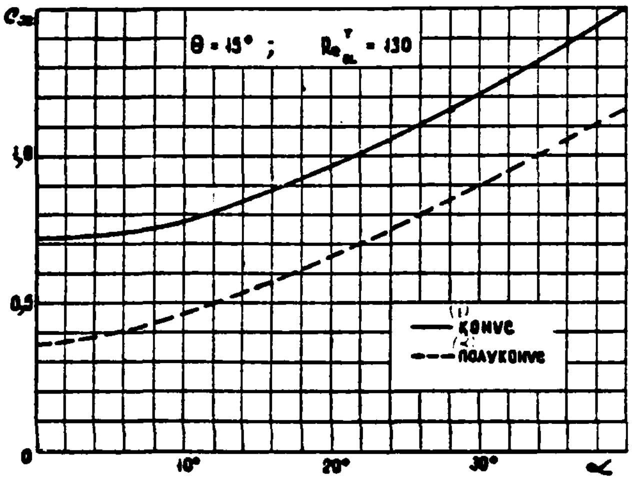

Fig. 124. Key: (1). cone. (2). semicone.

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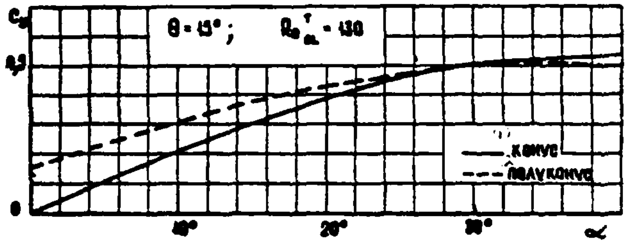

Fig. 125.

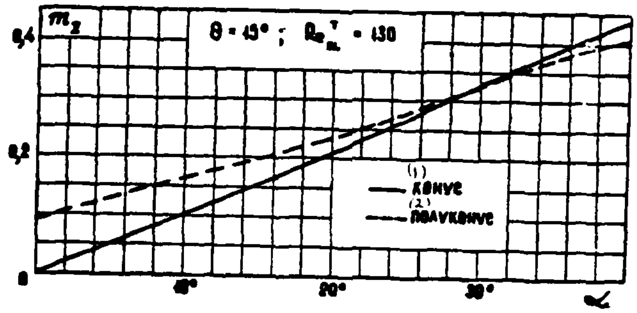

Fig. 126.

Fig. 125. Key: (1). cone. (2). semicone.

Fig. 126. Key: (1). cone. (2). semicone.

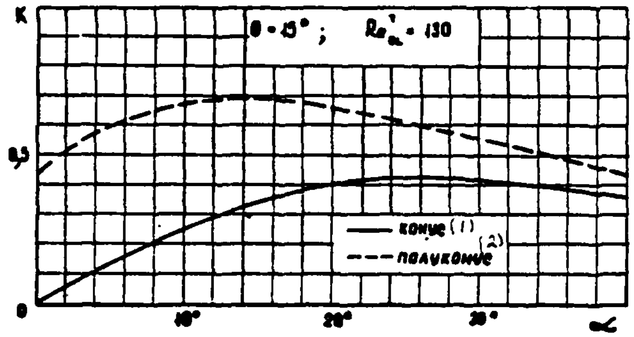

Fig. 127.

Key: (1). cone. (2). semicone.

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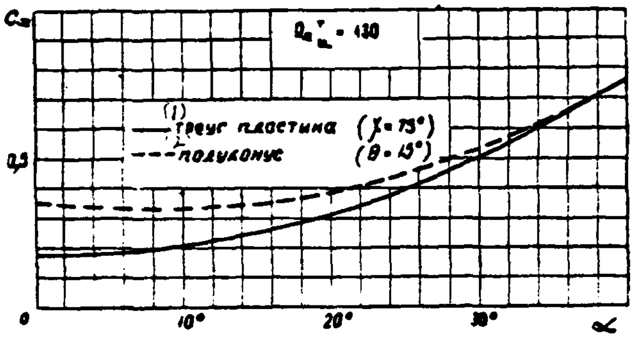

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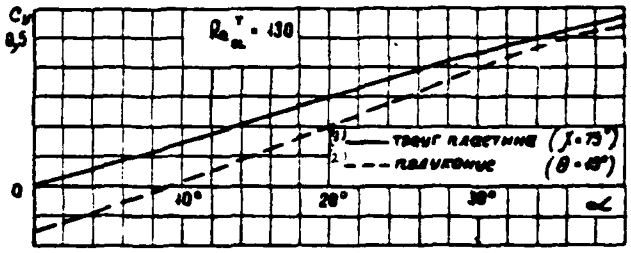

Fig. 129.

Fig. 128. Key: (1). triangular plate. (2). semicone.

Fig. 129. Key: (1). triangular plate. (2). semicone.

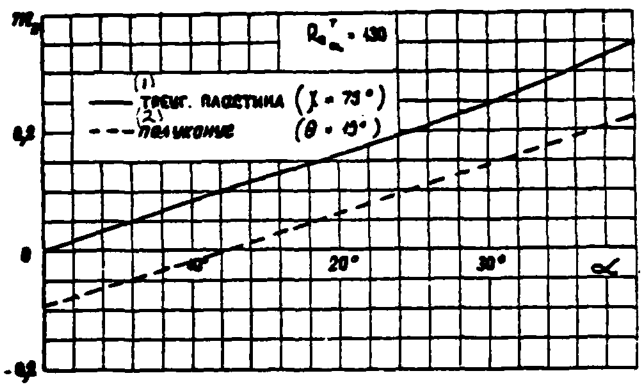

Fig. 130. Key: (1). triangular plate. (2). semicone.

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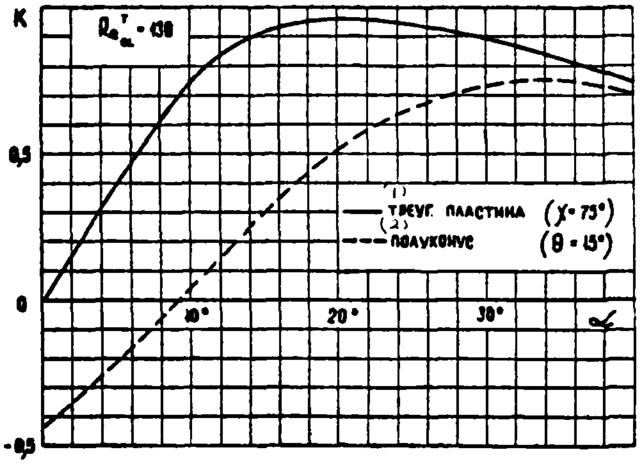

Fig. 131. Key: (1). triangular plate. (2). semicone.

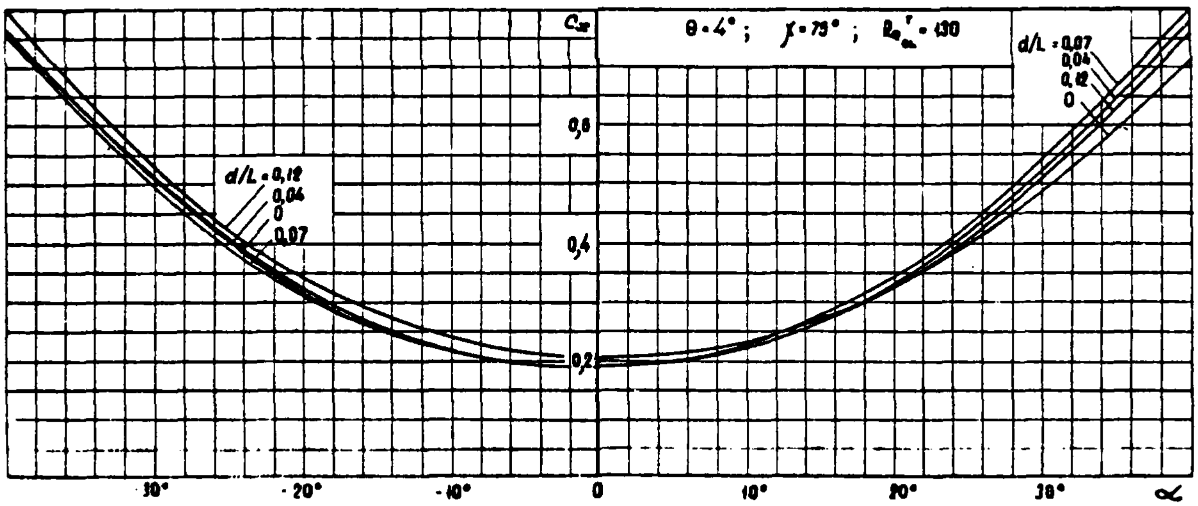

Fig. 132.

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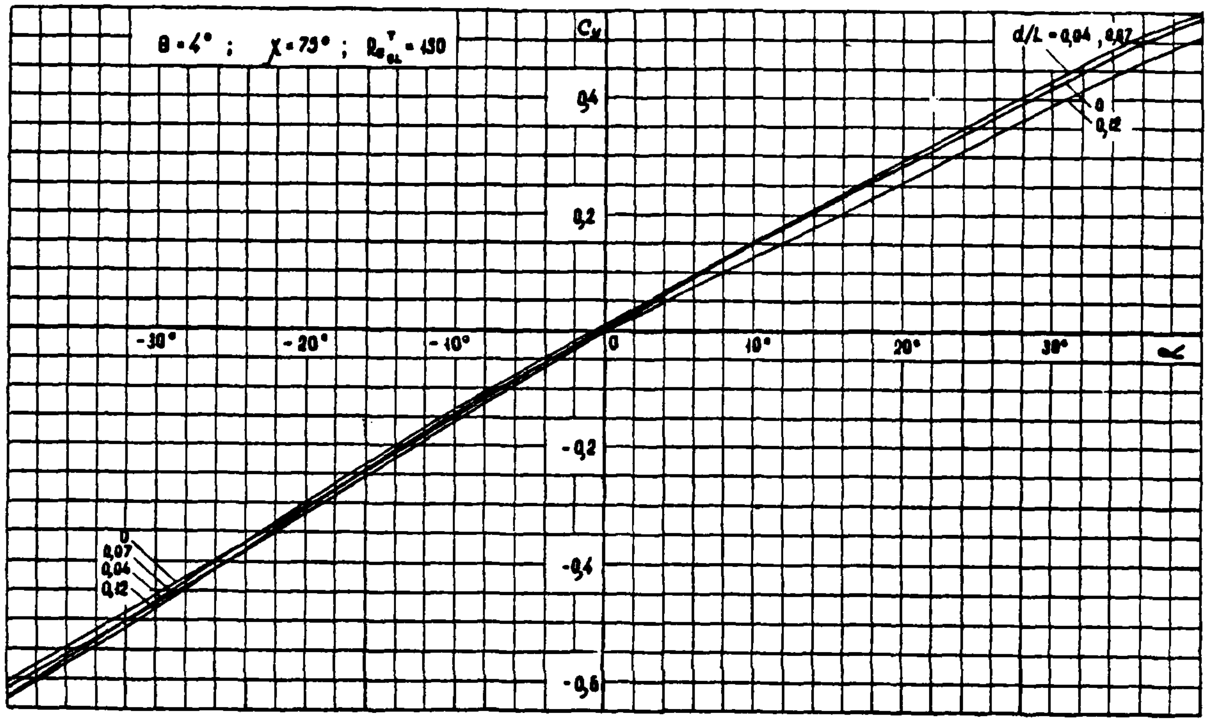

Fig. 133.

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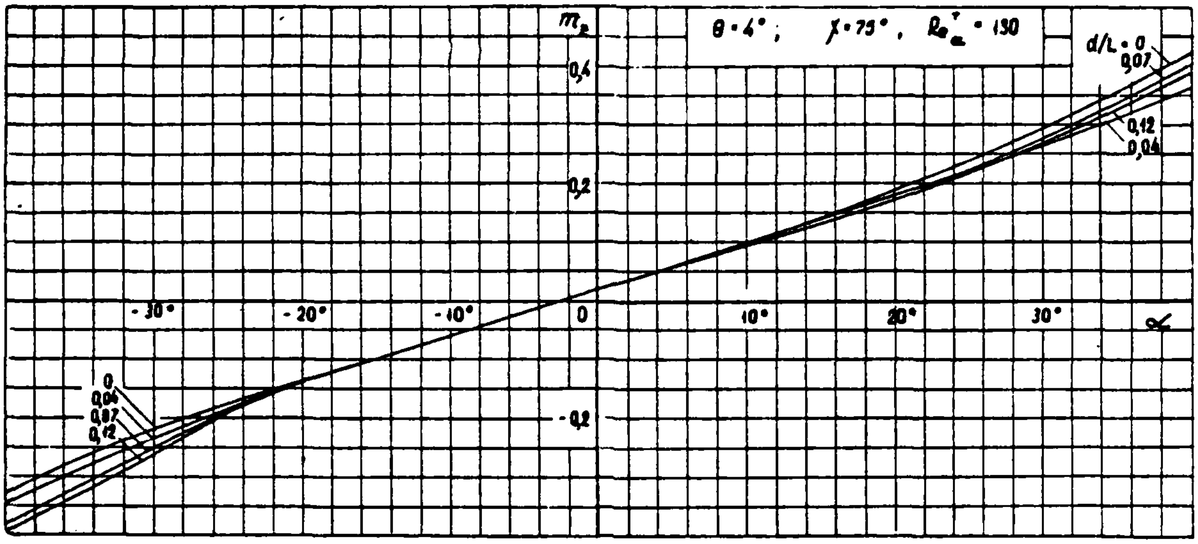


Fig. 134.

Page 50.

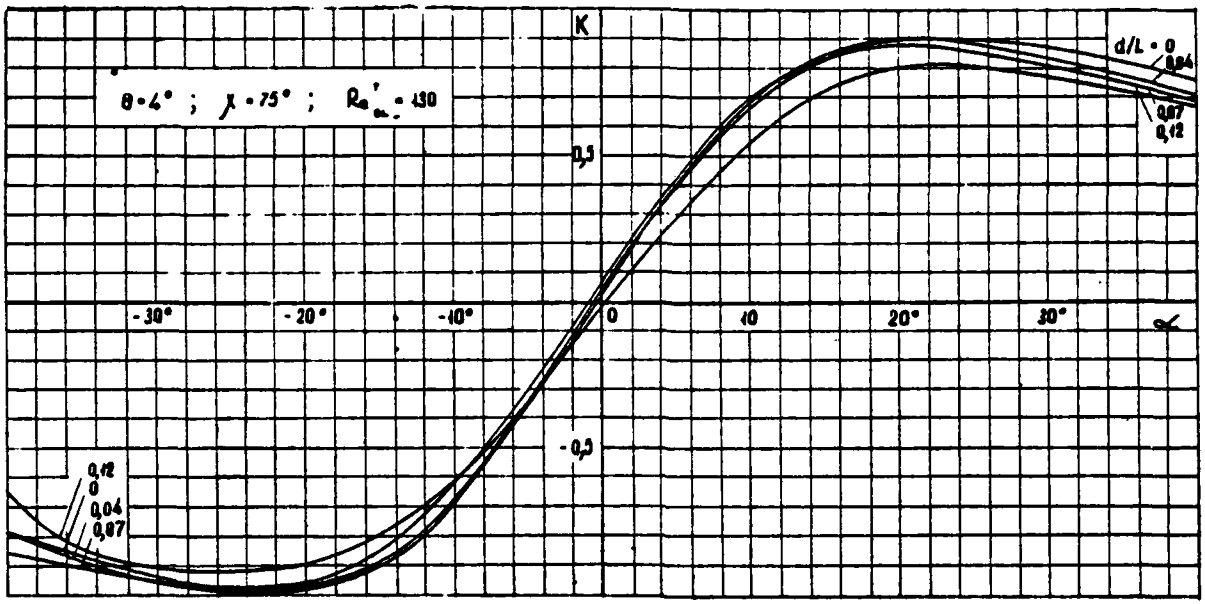
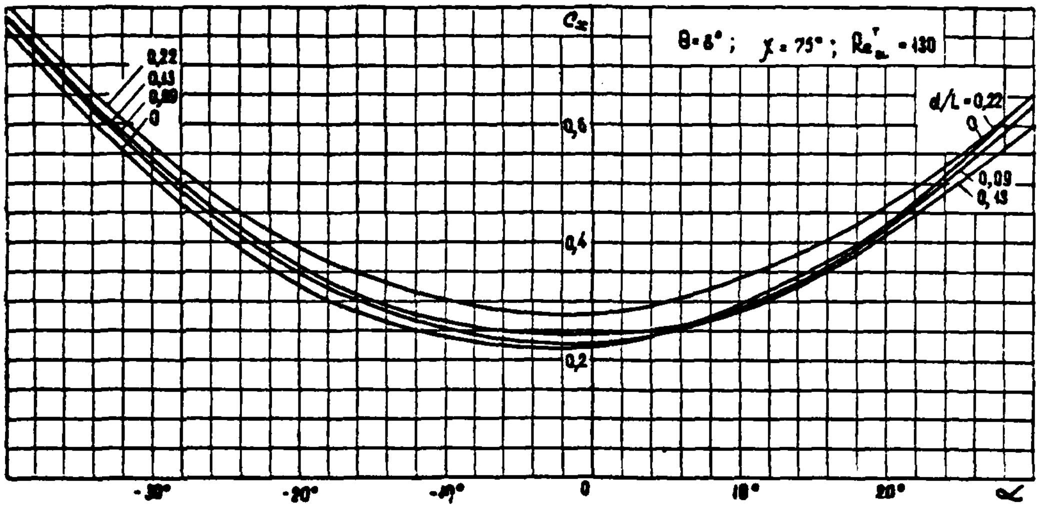


Fig. 135.

Page 51.



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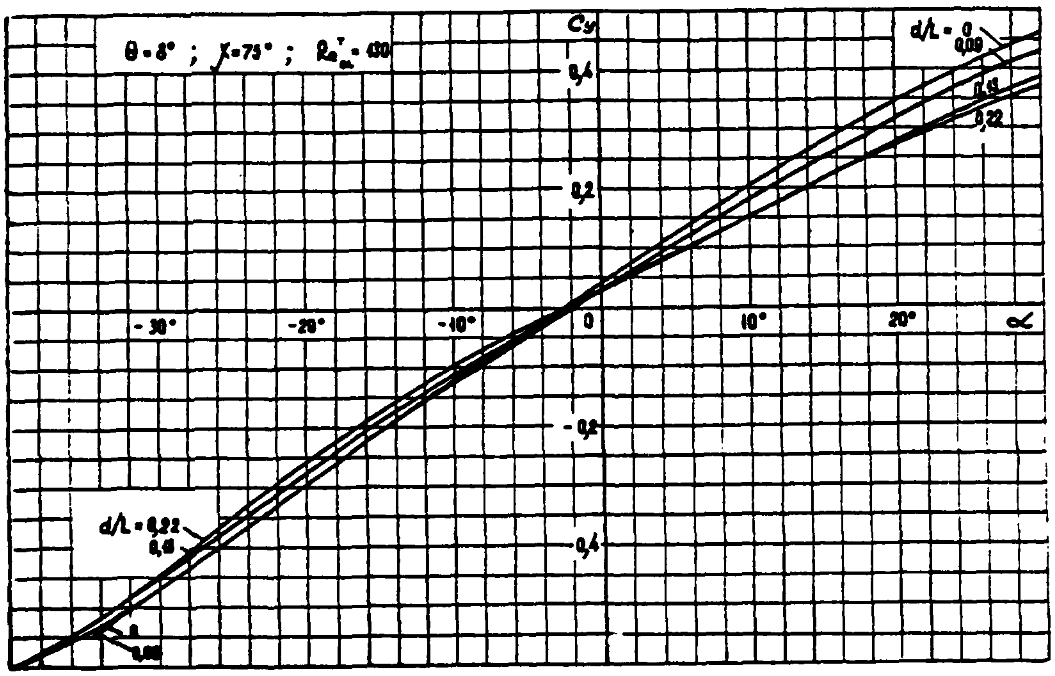

Fig. 137.

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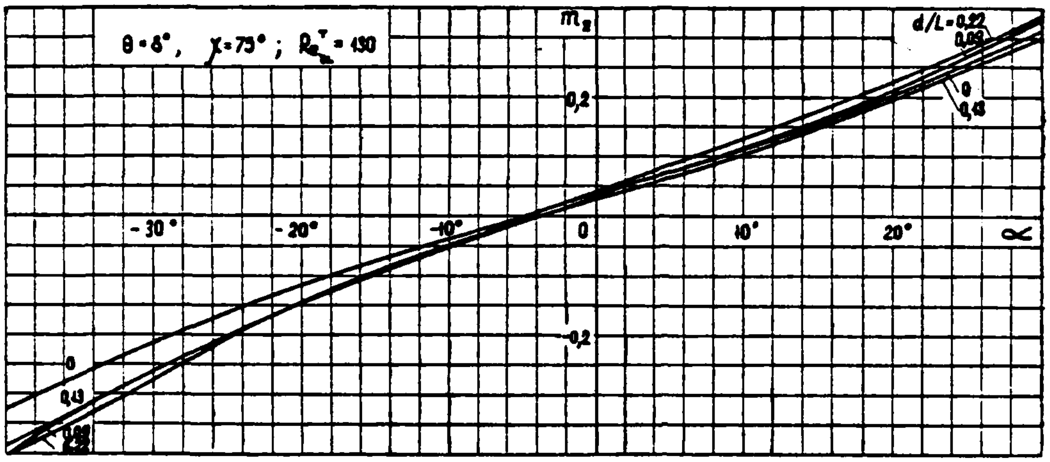

Fig. 138.

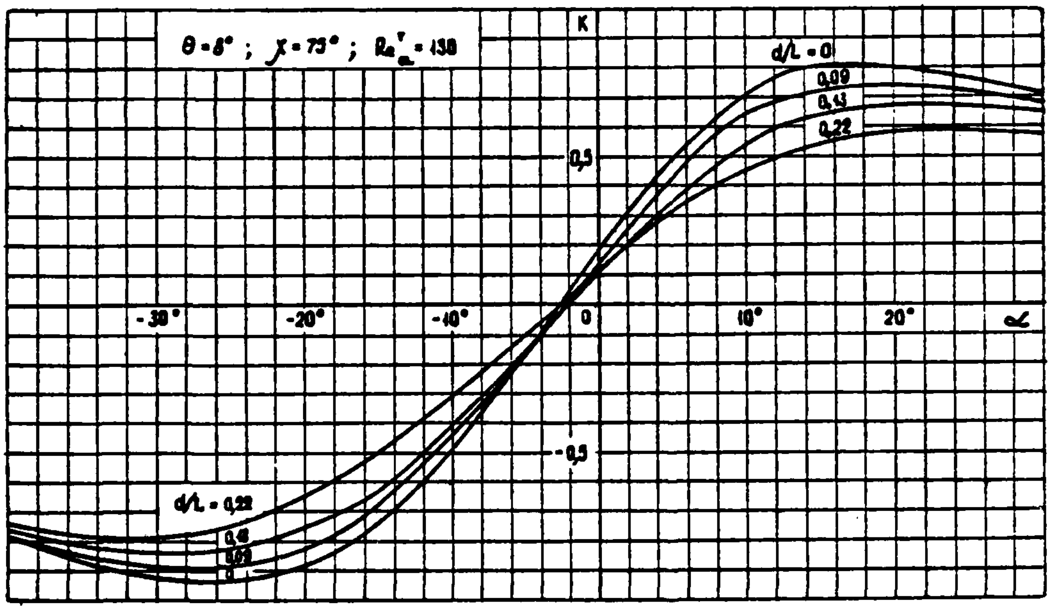

Fig. 139.

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APPLICATION OF THE MONTE CARLO METHOD IN DYNAMICS OF STRONGLY RAREFIED GAS.

V. A. Perepukhov.

Summary.

Are described setting, method and some results of solving the specific problems by the Monte Carlo method for two types of flows - free molecular and almost free molecular (the slight disturbance of free molecular flow).

CALCULATION OF FREE MOLECULAR FLOWS.

In the case of convex body the solution of the problem of free molecular [1] flow does not represent labor/work; however, during the study of flow by the free molecular flow of concave bodies and bodies of complex form it is necessary to consider the possibility of contact with the element/cell of the body surface of the molecules in

question, reflected from other elements/cells of surface or from other bodies, i.e., to consider interference.

FOOTNOTE [1]. Flow is free molecular, if the number of Knudsen $Kn=\lambda/\delta\to\infty$, where d - significant dimension of body, λ - minimum local mean free path of the molecules of gas. ENDFOOTNOTE.

Analogous situation appears also during the calculation of internal free molecular flows (for example, flows in the channels), when molecule, "stray" within the channel, can many times clash with its walls. In the most general/most common/most total setting such tasks for arbitrary law of reflection are examined in works [1-3]. The mathematical formulation of the problem for the concave bodies is given in work [1]. Fundamental equation is here the integral equation of Fredholm of the second order with the symmetrical kernel for the particle flux to the element/cell of the surface

$$N(dS_1)=N_\infty(dS_1)+\int_{S_1} N(dS_2)\,G(dS_1dS_2)\,dS_2, \qquad (1)$$

where $G(dS_1dS_2)$ - probability that the molecule reflected from element/cell dS_2 falls on the element/cell of surface dS_1. The solution of this equation in the general case presents great difficulties. Moreover, and the subsequent calculations of the aerodynamic characteristics of body require bulky calculations on computer(s).

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In this setting in works [4, 5] were calculated the aerodynamic characteristics of the circular cylindrical and spherical surfaces, converted by concave side to the flow, which encounters at the angle of attack α (Fig. 1). Since in these works it was disregarded with the thermal velocities of molecules in comparison with the macroscopic gas velocity and were not examined the cases, when some elements/cells of surface were shaded by others, then the obtained results were valid for the angles of attack α, which satisfy relationship/ratio $\alpha+\omega=\pi/2$, where ω - half-angle of the solution/opening of segment. The reflection of molecules from the surface was assumed to be diffuse. In work [4] was allowed the miscalculation, which then was corrected in [5]. If $S_\infty=\frac{U_\infty}{\sqrt{2RT_\infty}}\gg 1$, and the accommodation coefficient of energy $\alpha_E\approx 1$, then the temperature of the molecules $T_2=T_w\approx T_\infty$ reflected and the effect of concavity can be disregarded/neglected. In this case the interference of bodies in the free molecular flow will be determined only by the shading action of bodies on each other. In work [6] was undertaken the attempt compute the aerodynamic characteristics of the internal surface of hemisphere with arbitrary S_∞, however in it was allowed error in mathematical calculations and its results were not accurate. The aerodynamic characteristics of concave cylindrical surface when $S_\infty\geqslant 1$ were designed in work [7], moreover taking into account

shading/blanketing, i.e., with the arbitrary α. To the study of the interference of the groups of bodies in the free molecular flow is devoted a small number of works. Let us note, two of them. Work [8] examines the task of flow of the free molecular flow about two identical plates of the finite dimensions, perpendicular to each other and arranged/located at the zero angle of attack. Work [9] examines the task about the free molecular flow of gas in the flat ducts and the lattices.

During the calculation of internal flows in the majority of works is used the method of Clausing. Fundamental equation in this case is also the integral equation, analogous to that led above, for the flows of a number of particles to the element/cell of surface. For the tube of round cross section this equation takes the following form:

$$N(l) = N_1(l) + \int_0^l G(x)\,dN_2(x). \quad (2)$$

Here l - length of tube; $N_1(l)$ - a number of molecules, which fly without the collisions with the surface from the entrance to the output of tube; N_2 - number of molecules, which fly into the tube and encountering its surface at least one time; $G(x)dN_2(x)$ - a number of molecules which enter the tube and encounter wall in interval $x-(x+dx)$ and then either immediately or after further collisions they leave it. Basic difficulty during the use of this method consists in the determination of the form of the function $G(x)$. Examples of the calculation of internal courses by the method of Clausing can be found in a number of works (see for example, [10-12]).

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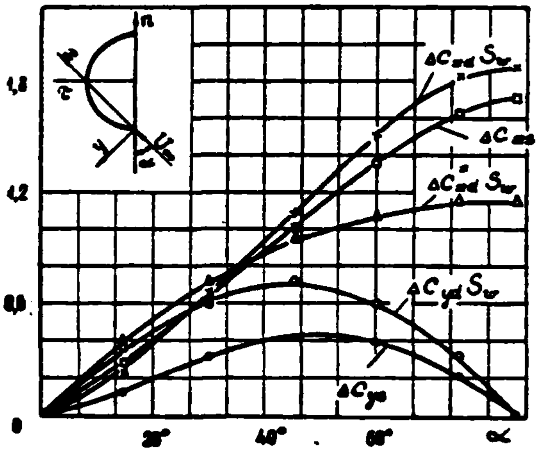

Fig. 1.

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For calculating the internal flows in works [13, 14] is used the Monte Carlo method, with the help of which were calculated the flows in the tubes of different configuration under the law of the diffuse reflection of molecules from the surface. The essence of the Monte Carlo method in connection with internal flows is reduced to the following. Let there be the tube with the section at entrance S_1 and at output S_2, then the gas flow through tube $N=N_1P_{12}-N_2P_{21}$, where N_1 - number of molecules, which fall into the tube through section S_1, and N_2 - a number of molecules, which fall into the tube through section S_2, P_{12} - probability that the molecule, which passed through section S_1, will reach section S_2. The procedure of determination P_{12}

and P_{21} is such. In section S_1 are developed with certain probability density the coordinates of the point from which begins its motion the molecule. Then with the probability density, which corresponds to the function of the distribution of molecules in the undisturbed flow, is developed the velocity vector of molecule. If particle immediately flies through the tube before section S_2, then from section S_1 is started new particle, in this case in the memory of electronic computer is memorized one. But if particle falls on the surface of tube, in accordance with law of reflection is developed the velocity vector of particle, which is reflected from the surface. When as a result of many reflections particle nevertheless achieves section S_2, then in the memory of machine is written/recorded one, but if particle achieves again section S_1, then - zero. The ratio of a number of particles N_l, of those flown from section S_1 to section S_2, to total number of particles N, launched in section S_1, approaches P_{12} with $N \to \infty$:

$$P_{12}=\lim_{N\to\infty}\frac{N_l}{N}. \quad (3)$$

Analogously is determined value P_{21}.

The use/application of the Monte Carlo method proved to be efficient and during the solution of the problems of external flow. For the first time this method was proposed and used in work [15], in which were determined the aerodynamic characteristics of the internal surface of hemisphere, which moves at a velocity, arbitrary according

to the value and the direction. During the calculation by the Monte Carlo method automatically drop out all difficulties, which appear during the determination of the aerodynamic characteristics of the isolated/insulated concave bodies, which have points of inflection, and especially the groups of bodies.

Formulation of the problem. Let us consider the overall diagram of the solution of the problem of free molecular flow of the Monte Carlo method about. Let us assume is assigned the body of arbitrary form (or the group of bodies). Let us assume that the flow of gas about the body everywhere free molecular, are assigned the function of the distribution of the molecules of the non-traveling flow and the law of interaction of molecules with the surface in any form, even in the form of table. It is first of all necessary to select the control surface whose form depends on the form of the function of the distribution of the molecules of the incident flow and on the shape of body. The only condition for its selecting is the following: not one molecule of the incident flow, which reaches body, must omit control surface. It is natural that it is better to choose this surface in such a way that it would take as less than the molecules, which fly past the body. Let us register the flow value of the molecules, which possess the speed in the range from $\vec{V}$ to $\vec{V}+d\vec{V}$, through the element/cell of control surface $d\bar{\Phi}$:

$$dN = f_\infty V^3 dV \sin\psi \cos\psi \, d\psi \, d\varphi \, d\bar{\Phi}, \tag{4}$$

where ψ - angle between the normal to element/cell $d\vec{\Phi}$ (standard/normal inside the control surface) and the direction of speed $\vec{V}$;

φ - orbital angle.

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We choose with certain probability density of the coordinate of element/cell of $d\vec{\Phi}$ on the control surface, velocity V and its direction, given by angles ψ and φ. We determine, did fall the flow of molecules dN on body surface (or one of the group of bodies). If the flow of molecules achieved body surface, then it brought into the point of entry/incidence on the surface the following molecular signs/criteria: the flow of molecules dN, pulse streams dNV_x, dNV_y, dNV_z in direction x, y, z, energy flow $(1/2)dNV^2$ and the "flow" of moment/torque $dN(\vec{R}\times\vec{V})$, where $\vec{R}$ - radius-vector of the point indicated. All these values are memorized in storage cells of computer(s). If on the body surface there is no accumulation of particles, then the arrived flow of molecules dN completely will be reflected from the surface, but if there is an accumulation, then will be reflected only the part of flow dN. The law of interaction of molecules with the body surface is assigned, i.e., is assigned the probability of reflection in this direction with the given speed;

therefore we develop with certain probability density the speed of the flow reflected and its direction. With the reflection the flow of molecules takes away from the surface the following molecular signs/criteria: the flow of molecules dN_{01}, pulse streams $dN_{01}V_{0x1}$, $dN_{01}V_{0y1}$, $dN_{01}V_{0z1}$ in directions x, y, z, energy flow $dN_{01}V^2_{01}/2$ and the "flow" of moment/torque $dN_{01}(\vec{R}x\vec{V}_{01})$. All these values are memorized in storage cells of computer(s).

Further we determine, crossed the flow reflected body surface or not. If it crossed, then we find the coordinates of point of intersection and send into storage cells of computer(s) the appropriate molecular signs/criteria and again develop reflection, etc. This process is continued until the flow of molecules dN_{0n} reflected after the n reflection flies out from the control volume. This entire process is called one testing. Furthermore, one testing is called such process when the flow of molecules dN after "starting/launching" from the control surface not at all intersects body surfaces and flies past it.

After conducting k of tests we compute local aerodynamic characteristics, summarizing all values of the corresponding molecular signs/criteria, memorized upon contact of the flow of molecules with the element/cell of body surface dF_j, and subtracting the sum of the corresponding molecular signs/criteria, memorized at

the moment of the reflection of the flow of molecules from element/cell dF_j. Difference we divide into a number of drawings k and a value of the area of element/cell dF_j.

During the calculation of total aerodynamic characteristics it is necessary to memorize molecular signs/criteria at the moment of the first entry/incidence of the flow of molecules dN to the surface and at the moment of its latter/last reflection, after which the particles will fly out from the control volume. Differences in the sums of these two values for the appropriate molecular signs/criteria are divided into a number of tests k.

Scanning/sweep of process on the time, i.e., successive tracking the particle fluxes dN, is possible because the molecules do not interact with each other and flow pattern can be then represented as the imposition of many flow patterns of body of the separate flows of molecules dN. It is possible to give another interpretation to the method presented. If we integrate expression (4) with respect to V, ψ, φ and over the entire control surface, then this integral N is equal to total number of molecules, which fly through the control surface. Ratio dN/N is nothing else but the probability of the flight/span of molecules from this by speed $\vec{V}$ through this point control surface.

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Then, after making the procedure described above not for the flow of molecules dN, but for one molecule, it is possible to compute the average/mean values of the aerodynamic characteristics, which correspond to one molecule, which flies through the control surface. For the determination of the aerodynamic characteristics of body, determined by the total flux of its reaching molecules, it is necessary the mentioned above aerodynamic characteristics, calculated for one molecule, to multiply by the flow value of molecules N through the control surface. These two approaches correspond in a sense by known in the method Monte Carlo to the diagrams of uniform and essential selection. In the diagram of essential selection the accuracy with the given number of tests is above, but in certain cases the use/application of this diagram causes difficulty due to the sharp increase in the number of computer operations, connected with obtaining of random numbers with the assigned law of distribution from the uniform sequence.

The calculations of aerodynamic characteristics were performed for the cases of diffuse and mirror laws of reflection; therefore will be given below basic formulas for the drawing of the "start" of particle from the control surface and the formula for the drawing of the report/event of the reflection of particle from the body

(analogous formulas can be obtained also for the arbitrary law). Let to the quiescent body attack the flow of molecules the function of distribution of which takes the following form:

$$f_\infty = n_\infty (2\pi R T_\infty)^{-3/2} \exp\left\{-\frac{1}{2RT_\infty}[(V_x - U_{\infty x})^2 + (V_y - U_{\infty y})^2 + (V_z - U_{\infty z})^2]\right\}.$$

Then flow dN (y axis is directed along the normal to $d\bar{\Phi}$) can be registered thus:

$$dN = \frac{n_\infty U_\infty}{2} b \left\{\frac{e^{-(bS_\infty)^2}}{\sqrt{\pi} b S_\infty} + [1 + \Phi(\sqrt{2} b S_\infty)]\right\} \bar{\Phi} \times$$

$$\times f(V_y) f(V_x) f(V_z) dV_x dV_y dV_z \frac{d\bar{\Phi}}{\bar{\Phi}};$$

$$f(V_x) = \frac{1}{\sqrt{\pi}} e^{-(V_x - aS_\infty)^2};$$

$$f(V_y) = \frac{1}{A_0} V_y e^{-(V_y - bS_\infty)^2};$$

$$f(V_z) = \frac{1}{\sqrt{\pi}} e^{-(V_z - cS_\infty)^2};$$

$$N = \int dN = n_\infty U_\infty \frac{b}{2} \left\{\frac{e^{-(bS_\infty)^2}}{\sqrt{\pi} b S_\infty} + [1 + \Phi(\sqrt{2} b S_\infty)]\right\} \bar{\Phi}.$$

In these formulas

$$U_{\infty x} = U_\infty a; \quad U_{\infty y} = U_\infty b; \quad U_{\infty z} = U_\infty c;$$

$$a^2 + b^2 + c^2 = 1;$$

$$V_i = \frac{v_i}{\sqrt{2RT_\infty}}; \quad S_\infty = \frac{U_\infty}{\sqrt{2RT_\infty}};$$

$$A_0 = \frac{1}{2}\left\{e^{-(bS_\infty)^2} + \sqrt{\pi} b S_\infty [1 + \Phi(bS_\infty \sqrt{2})]\right\}.$$

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The probability of the "start" of molecule from the point of

control surface with coordinates $d\bar{\Phi}$ at a rate of $\bar{v}$ is equal to

$$\eta=\frac{dN}{N}=f(V_x)f(V_y)f(V_z)\,dV_x\,dV_y\,dV_z\,\frac{d\bar{\Phi}}{\bar{\Phi}}.$$

Let us take the known procedure of obtaining random numbers with the assigned law of distribution from pseudorandom numbers [16], evenly distributed in the interval [0; 1]. For V_x, V_y, V_z it consists of the following. Since when $V_{0y}=V_{y\max}+3$ (where $V_{y\max}$ — value V_y, with which $f(V_y)=f_{\max}(V_y)$) function f is in effect equal to zero, let us bound the range of change V_y by interval $[0, V_{0y}]$:

$$V_{0y}=\frac{1}{2}(S_\infty b+\sqrt{2+b^2S_\infty^2})+3.$$

Let $V_y^*=\frac{V_y}{V_{0y}}$, $0\leqslant V_y^*\leqslant 1$, $f^*(V_y^*)=\frac{f(V_y^*)}{f_{\max}(V_y^*)}$, so that

$$f_{\max}(V_y^*)=f\left(\frac{S_\infty b+\sqrt{2+b^2S_\infty^2}}{2V_{0y}}\right).$$

As a result of simple conversions we obtain

$$f^*(V_y^*)=\frac{2\left[\frac{1}{2}(bS_\infty+\sqrt{2+b^2S_\infty^2})+3\right]V_y^*}{bS_\infty+\sqrt{2+b^2S_\infty^2}}\times$$
$$\times\exp\left\{\left[\frac{1}{2}(\sqrt{2+b^2S_\infty^2}-bS_\infty)\right]^2-\left\{\left[\frac{1}{2}(bS_\infty+\sqrt{2+b^2S_\infty^2})+3\right]\times\right.\right.$$
$$\left.\left.\times V_y^*-bS_\infty\right\}^2\right\}.$$

Further from the sequence of the random numbers evenly distributed in interval [0, 1] we choose two numbers (ξ_1 and ξ_2) and we check inequality $\xi_1<f^*(\xi_2)$. If inequality is fulfilled, then

$$V_y=\xi_2V_{0y}\sqrt{2RT_\infty}=\xi_2\frac{V_{0y}}{S_\infty}U_\infty.$$

For V_x and V_z the procedure is analogous. For their drawing are valid the following formulas

$$\xi_3\leqslant\exp[-(6\xi_4-3)^2];$$
$$\xi_5\leqslant\exp[-(6\xi_6-3)^2].$$

With executing of first inequality we have

$$V_x = \frac{(6\xi_4 + S_\infty a - 3)}{S_\infty} U_\infty,$$

with executing of second inequality we have

$$V_x = \frac{(6\xi_6 + S_\infty c - 3)}{S_\infty} U_\infty.$$

Let us register the flow of the diffuse reflected molecules with the function of velocity distribution

$$f = n_w (\pi 2RT_w)^{-3/2} \exp[-(2RT_w)^{-1} V^2]$$

from the element/cell of body surface dF:

$$dN_w = n_w (\pi 2RT_w)^{-3/2} \exp[-(2RT_w)^{-1} V^2] V^3 \sin\psi \cos\psi d\psi\, d\varphi\, dV\, dF.$$

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Total number of molecules, reflected from element/cell dF, is equal

$$N_w = \int dN_w = n_w \frac{\sqrt{2RT_w}}{2\sqrt{\pi}} dF.$$

The probability of reflection with this speed V in this direction (θ, μ) is equal to

$$\frac{dN_w}{N_w} = f(V) f(\theta) f(\mu)\, dV\, d\theta\, d\mu,$$

where

$$f(V) = 2V^3 e^{-V^2} dV; \quad f(\theta) = 2\sin\theta\cos\theta;$$

$$f(\mu) = \frac{1}{2\pi}; \quad V = \frac{v}{(2RT_w)^{1/2}}.$$

Formulas for the drawing θ, μ:

$$\sin\theta = \sqrt{\xi_i}; \quad \mu = 2\pi\xi_{i+1}.$$

For drawing V is applicable this procedure. We choose ξ_j and ξ_{j+1} and we require executing of the inequality

$$\xi_j \leqslant \left[\left(\frac{2}{3}\right)^{1/2} k_1 \xi_{j+1}\right]^3 \exp\left(-k_1^2\xi_j^2 + \frac{3}{2}\right).$$

If it is carried out, then $V = \xi_j k_1$, where k_1=3. For the law of mirror reflection $V_{y\,пад} = -V_{y\,отр}$, $V_{x\,пад} = V_{x\,отр}$, $V_{z\,пад} = V_{z\,отр}$.

By this method were carried out the calculations of the aerodynamic characteristics of the following bodies: the hemisphere, converted by concave side to the flow at arbitrary value S_∞ [15]; cylinder with the spherical blunting and the blades/vanes, arranged/located perpendicularly to the axis of cylinder; the body, which consists of the hemisphere and the circle and arranged/located under the angle of attack; the body of that consisting of the cylinder, the blades/vanes and the cone; the body, which consists of three cones with the spherical blunting; the body, which consists of the cylinder with the spherical blunting and disk [17]. For an example we analyze the results of calculating the aerodynamic characteristics of hemisphere and body, which consists of the cylinder, blades/vanes and cone.

Hemisphere. The aerodynamic characteristics of hemisphere were determined for the laws of diffuse and mirror reflection. Any aerodynamic characteristic can be registered in the form

$$\Pi_i = \Pi_{i\infty} + \Delta\Pi_{i0}.$$

Here $\Pi_{i\infty}$ — aerodynamic characteristic of body in the free

molecular flow, encompassing the aerodynamic characteristic of the internal part of the surface without taking into account of reflection and exterior of the surface taking into account reflection; $\Delta\bar{\Pi}_{10}$ is caused by interference.

Fig. 1 gives dependence Δc_x, Δc_y and $\Delta c_x^* = \frac{2}{3} S_w^{-1} \pi^{-1/2} (2\alpha + \sin 2\alpha)$ (taking into account only the first reflection of molecules from the internal surface) on α when $S_\infty = \infty$. Index d corresponds to diffuse reflection, index s - mirror; $S_w = \frac{U_\infty}{\sqrt{2RT_w}}$, where T_w — temperature of the molecules reflected. Fig. 2 depicts the dependence of addition to the value of the "flow of moment/torque" $\Delta\bar{E}_d$ from

$$\alpha \left(\Delta M_{zd} = \Delta\bar{M}_{zd} \frac{mn_\infty U_\infty^2 \pi R_0^3}{S_w} \right).$$

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Fig. 3 depicts dependence $\Delta\bar{E}_d$ on $\alpha \left(\Delta E_d = \Delta\bar{E}_d \frac{mn_\infty U_\infty^3 \pi R_0^2}{2S_w^2} \right)$. Let us note that here in the case of completely diffuse reflection the interference of molecules plays no role and value $\Delta E_d = \Delta E_d^*$, where ΔE_d^* — correction only due to the first reflection of molecules from the internal surface of hemisphere. This fact can serve as the further testing of the accuracy of method.

In the free molecular flow for the computed aerodynamic characteristics in the case of the laws of diffuse and mirror

reflection taking into account the effect of the exterior of the surface are valid the following formulas:

with the diffuse reflection

$$c_x = c_{x1} + c_{x2} + \Delta c_{xd}; \quad c_y = c_{y2} + \Delta c_{yd}; \quad M_z = M_{z2} + 2\Delta M_{zd};$$

$$c_{x1} = 2\sin\alpha; \quad c_{x2} = 2\sin^2\left(\frac{\pi}{4} - \frac{\alpha}{2}\right) - \pi^{-1/2}(\pi - 2\alpha + \sin 2\alpha)(3S_\infty)^{-1};$$

$$c_{y2} = -\frac{2}{3}\pi^{1/2} S_\infty^{-1}\cos^2\alpha; \quad M_{z2} = -\frac{4}{3}\pi^{-1}\cos^2\alpha;$$

$$c_E = c_{E1} + c_{E2} + \Delta c_E; \quad c_{E1} = \sin\alpha;$$

$$c_{E2} = \left(1 - \frac{2}{S_\infty^2}\right)\sin^2\left(\frac{\pi}{4} - \frac{\alpha}{2}\right);$$

$$\Delta c_E^{\bullet} = \Delta c_E = -\frac{2}{S_\infty^2}\sin\alpha;$$

with the mirror reflection

$$c_x = c_{x1} + c_{x2} + \Delta c_{xs}; \quad c_y = c_{y2} + \Delta c_{ys};$$

$$c_{x1} = 2\sin\alpha; \quad c_{x2} = 2(2 + \sin\alpha)\sin^4\left(\frac{\pi}{4} - \frac{\alpha}{2}\right); \quad c_{y2} = -\frac{1}{2}\cos^3\alpha.$$

Here coefficients c_x and c_y are related to $0,5\,\pi R_0^2 m n_\infty U_\infty^2$, moment/torque is calculated relative to the center of sphere and is related to $0,5\,\pi R_0^3 m n_\infty U_\infty^2$, coefficient c_E is related to $0,5\,\pi R_0^2 m n_\infty U_\infty^3$. Index 1 designates the internal part of the surface of hemisphere in the free molecular flow without taking into account reflection, index 2 - the exterior of the surface in the free molecular flow taking into account reflection. From the calculations conducted it follows that the interference has an effect on different aerodynamic characteristics differently. The most sensitive value is c_y.

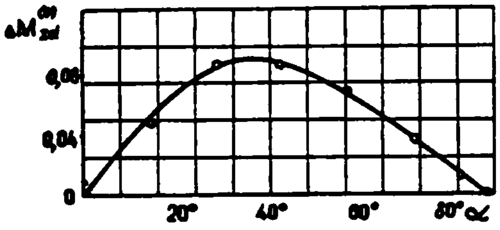

Fig. 2.

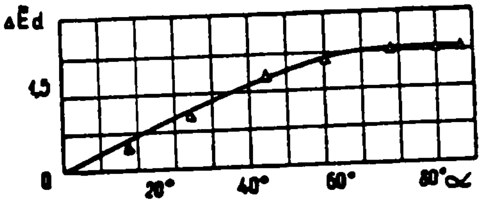

Fig. 3.

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In the case of the law of diffuse reflection the interference plays important role for all aerodynamic characteristics, if only body surface has sufficiently high temperature, i.e., $S_w \approx 1$.

Body, which consists of the cylinder, blades/vanes and cone (Fig. 4). Calculation was carried out at θ=45°, $R_1=L_1=L_3$. All geometric dimensions are related to $R=L_1+L_2/2\ [1+(R_1+L_3/L_2)^2]$. Formulas for any aerodynamic characteristic are written/recorded in the form $\Pi_i = \Pi_{i\infty} + \Delta\Pi_i$, where $\Pi_{i\infty}$ is determined by first contact of molecules with body; $\Delta\Pi_i$ — correction, caused by interference and first reflection. At α>90° it is necessary to consider the effect of the end/face of cylinder on the aerodynamic characteristics. In this case any aerodynamic characteristic is written/recorded in the form

$$\Pi_l = \Pi_{l\infty} + \Delta\Pi_l + \Pi_{l\infty\tau} + \Delta\Pi_{l\tau},$$

where $\Pi_{l\infty\tau}$ is determined by the molecules, falling on the end/face from infinity, $\Delta\Pi_{l\tau}$ – by the molecules reflected from the end/face.

In the case of diffuse reflection

$$P_{\infty\tau x} = -mn_\infty U_\infty^2 \pi R_1^2 \cos\alpha \sin\alpha; \quad \Delta P_{\tau x} = 0;$$

$$P_{\infty\tau y} = -mn_\infty U_\infty^2 \pi R_1^2 \cos^2\alpha; \quad \Delta P_{\tau y} = -\pi R_1^2 mn_\infty U_\infty^2 \frac{\sqrt{\pi}}{S_w} \cos\alpha.$$

In the case of the mirror reflection

$$P_{\infty\tau y} + \Delta P_{\tau y} = -2mn_\infty U_\infty^2 \pi R_1^2 \cos^2\alpha.$$

Fig. 5-8 gives the dependences of dimensionless aerodynamic characteristics $P_{\tau\infty}$, $P_{N\infty}$, E_∞, $M_{z\infty}$ on the angle of attack α. Corrections to the aerodynamic characteristics in the case of diffuse reflection are given for Fig. 9-11, in the case of mirror reflection - for Fig. 12-14. From the given results follows the conclusion that the interference exerts a substantial influence on c_y and M_z in the case of mirror and diffuse reflection and "hot" wall.

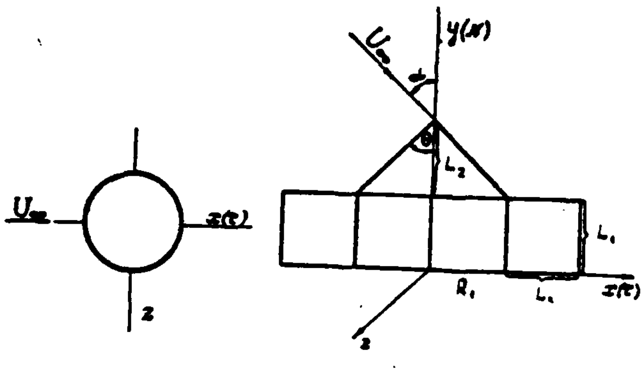

Fig. 4.

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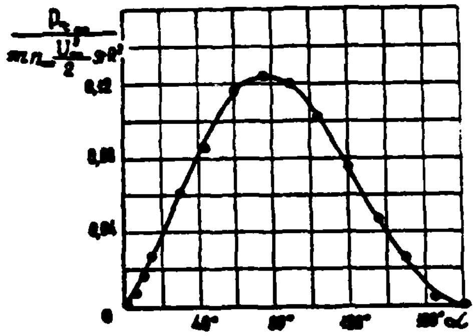

Fig. 5.

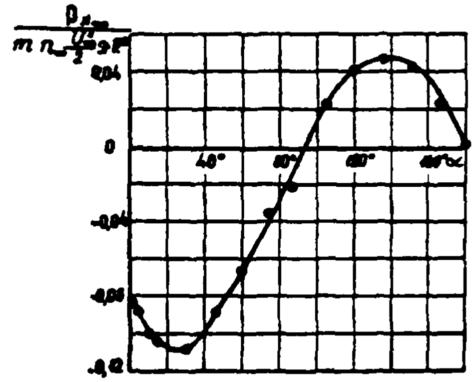

Fig. 6.

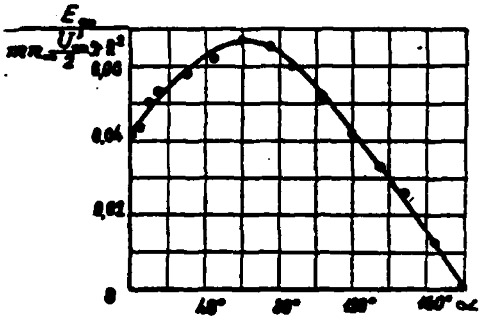

Fig. 7.

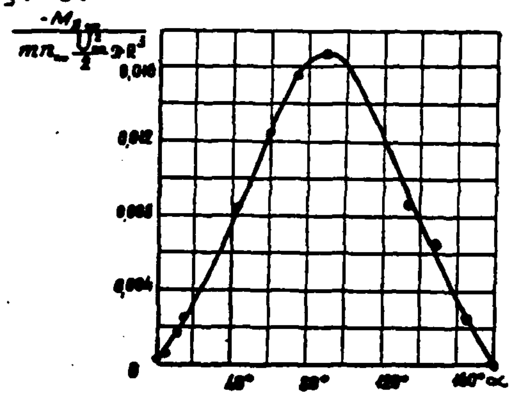

Fig. 8.

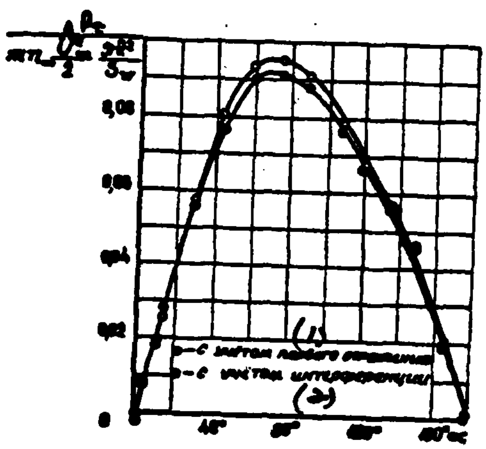

Fig. 9.

Fig. 9.

Key: (1). taking into account the first reflection. (2). taking into account interference.

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From the numerous calculations conducted it is possible to draw the following general/common/total conclusions:

- if molecules are reflected from the body, which has one significant dimension, with speed, there is much lower speed of the molecules of the incident flow, then the basic contribution to the interference is determined by shading/blanketing the some parts of the body by others;

- if body has the large surfaces, situated in parallel to the incident flow, then interference can exert a substantial influence on the value of some aerodynamic characteristics even in the case of "cold" body;

- interference can very substantially affect aerodynamic characteristics in the case of hot wall, i.e., when molecules are reflected at a velocity, equal in order of velocity of incident flow.

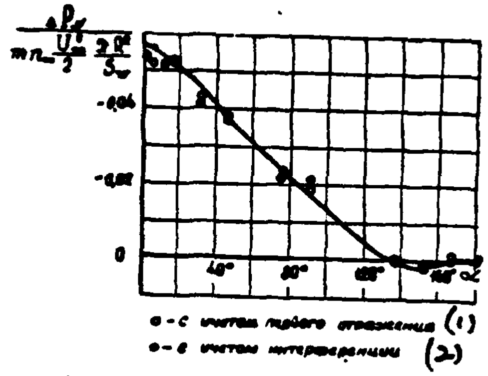

Fig. 10.

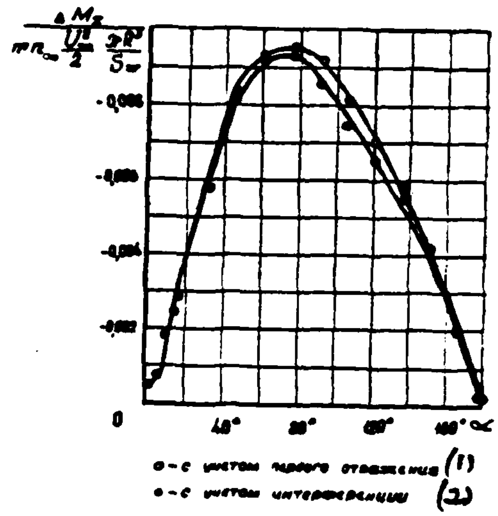

Fig. 11.

Key: (1). taking into account the first reflection. (2). taking into account interference.

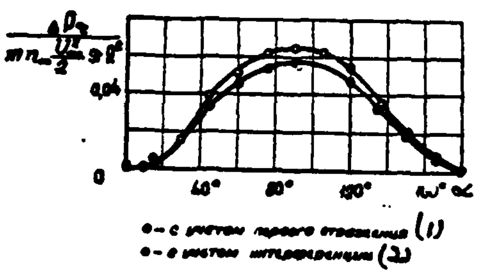

Fig. 12.

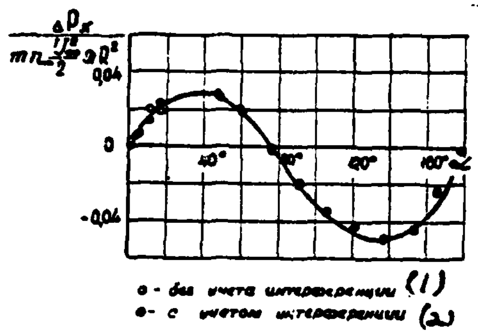

Fig. 13.

Key: (1). taking into account the first reflection. (2). taking into account interference.

Key: (1). without taking into account interference. (2). taking into account interference.

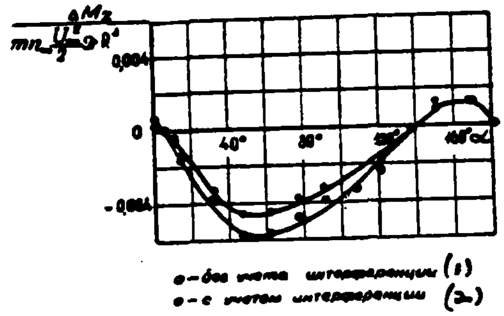

Fig. 14.

Key: (1). without taking into account interference. (2). taking into account interference.

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Calculation of flows, close to free molecular.

With the decrease of the local Knudsen number the collisions of molecules begin to play the significant role in the flow pattern of body and must be considered them. During the determination of the distribution function for the flow, different from the free molecular, it is possible to use the formal resolution of the solution of the equation of Boltzmann in the series/row for 1/Kn.

Attempt to find solution in this form taking into account in essence only of the terms of order 1/Kn they were undertaken in works [18-20]. However, for this case of lining/calculation they were very bulky and the obtained results did not have practical interest. In work [21] was for the first time proposed the theory, which was subsequently called the theory of the first intermolecular collisions. Was solved the problem about resistance of the circular disk, arranged/located normal to impinging hyperthermal flow of molecules, in this case was considered the correction to resistance in the free molecular flow due to the single collisions between the molecules reflected and the molecules of the incident flow. Within the framework of the theory of the first intermolecular collisions were evaluated the aerodynamic characteristics of infinite band [22], infinite cylinder [23] and sphere [24] (in the linings/calculations of latter/last work was allowed the error, which led to the fact that the obtained allowance of the value of drag coefficient in the free flow was overstated approximately/exemplarily doubly).

Several on another path went in his studies of flows, close to the free molecular ones, Willis [25]. He used instead of the equation of Boltzmann the modified model equation of Crooke and he computed his first approximation, after making for the zero approximation free molecular decision. The formulation of the problems in this form is qualitatively close to the formulation of the problem in the theory

of the first intermolecular collisions. To a deficiency/lack in this method it is necessary to relate the use of model equation of Crooke whose suitability is doubtful for the flows, distant from the equilibrium ones. Furthermore, and in the case of model equation linings/calculations are bulky, so that calculations were carried out only for the sphere, cylinder [26] and flow of Couette [25]. In work [27] for calculating the aerodynamic characteristics of sphere was used the method of resolving the solution of the model equation of Crooke in the series/row for 1/Kn and was found the first term of series/row; the obtained results qualitatively coincide with results [26]. In works [28, 29] was used the method of successive approximations for the integral kinetic equation, for which was designed the first approximation. In particular, in [28] was determined stagnation pressure of the mirror reflecting sphere.

The most complete analysis of the flows, close to the free molecular ones, was carried out in the work of M. N. Kogan [30, 31]. In particular, in them it was shown that in the theory of the first intermolecular collisions for the convex finite bodies in the cases, which are of practical interest, it is necessary to seek corrections and to the free molecular value of aerodynamic characteristics only due to the single collisions between the molecules, reflected from the body, and by the molecules of the incident flow. These works examine also a question about the limits of the applicability of the

theory of the first collisions, are qualitatively analyzed the basic types of the flows, which have practical interest both for the "cold ones" and for the "hot" bodies (i.e. for the actual conditions and the test conditions in the indraft wind tunnels), are indicated the similarity parameters and the methods of the recalculation of obtained theoretical data to the actual conditions and the conditions for experiment in the wind tunnels.

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M. N. Kogan also showed that if we use the formal method of solving the equation of Boltzmann, expanding the distribution function in series/row according to 1/Kn, then the solution, found with an accuracy down to the terms 1/Kn, corresponds to the theory of the first intermolecular collisions. Use/application of the Monte Carlo method in the theory of the first intermolecular collisions made possible to create the universal calculation method, which makes it possible to determine the aerodynamic characteristics of convex bodies under arbitrary law of reflection of molecules from the body and arbitrary law of interaction between the molecules.

Formulation of the problem. Since during the motion of flight vehicle at the high altitudes its speed, as a rule, is much more than the average/mean thermal velocity of molecules, then we during the

solution of the problems of [illegible] disregard the thermal velocity of the molecules of the [illegible] in comparison with its macroscopic speed and [illegible] the body attacks the hyperthermal flow with a sp[illegible] it was said, that in the theory of the first [illegible] it is necessary to examine only the collisions between [illegible] [illegible]cules, reflected from the body, and by the molecules of the [illegible] flow.

Let us register the number of collisions, which occur in certain volume element between the molecules, reflected from the element/cell of surface dF with the speeds in the range from $\vec{V}_1$ to $\vec{V}_1+d\vec{V}_1$ and the molecules of the incident flow per unit time in the element of volume $d\vec{r}$:

$$dN=f_\infty(\vec{V}_1)f_w(\vec{V}_2)\,g_{12}^{\frac{s-5}{s-1}}\,b\,(2k)^{\frac{2}{s-1}}\,db\,d\varepsilon\,d\vec{V}_1\,d\vec{V}_2\,d\vec{r}.$$

If this expression is integrated over entire physical and high-speed/high-velocity space, then we will obtain total number of collisions N per unit of time. Ratio dN/N is nothing else but the probability of this collision. The collisions of molecules in a two-fold manner affect the aerodynamic characteristics of the body: on one hand, due to the collisions to the body comes the further flow of molecular signs/criteria, on the other hand, due to the collisions to the body does not come certain flow of the molecular signs/criteria which carried from infinity of molecule, which clashed with the molecules, reflected from the body. Consequently, for any

aerodynamic characteristic of body taking into account the first collisions is valid the recording: $\Pi_i = \Pi_{i\,c.м} + \Pi_{i+} - \Pi_{i-}$, where $\Pi_{i\,c.м}$ — value of aerodynamic characteristic in the free molecular flow; Π_{i+} — addition, caused by collisions; Π_{i-} — loss due to the collisions. Developing randomly the sufficiently large number of collisions K in the space, it is possible to determine the local and total values of the aerodynamic characteristics of body, averaging additions Π_{i+} and Π_{i-} according to the number of collisions K. If molecules are reflected from the body with the average speed which is much lower than the speed of the molecules of the incident flow, then at the moment of colliding the molecules it is possible to consider that the speed of the molecule reflected is equal to zero; this assumption makes it possible to find in the form of quadratures the function of the distribution of molecules on the body. In this case the Monte Carlo method is applied to the calculation of the repeated integrals, through which are written/recorded the aerodynamic characteristics of body.

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Let us illustrate based on the example of the flow around sphere, how occurs the simulation of flow pattern with the help of the Monte Carlo method. Let us introduce the following assumptions: 1) the reflection of molecules from the body occurs according to the

diffuse law, 2) molecules are elastic spheres by diameter σ. Let us introduce dimensionless parameters $S_w = \frac{U_\infty}{\sqrt{2RT_w}}$ and $Kn_\infty = \frac{1}{2\sqrt{2}\pi\sigma^2 n_\infty R_0}$, where T_w — temperature of the reflected according to the Maxwellian law molecules

$$f = n_w (2\pi RT_w)^{-3/2} \exp\left(-\frac{v^2}{2RT_w}\right);$$

R - gas constant; $\pi\sigma^2$ - collision cross section for the solid spheres; n_∞ — density at infinity.

Let us register the number of collisions, which occur at point A(x, y, z) (Fig. 15) between the molecules, reflected from element/cell dF of the surface of sphere with the speeds in the range $\vec{v}$, $\vec{v}+d\vec{v}_1$, and by the molecules of the incident flow per unit time in the element of volume $\rho^2 d\rho \sin\psi \, d\psi \, d\varphi$:

$$dN = n_\infty n_w (2\pi RT_w)^{-3/2} \exp\left(-\frac{v^2}{2RT_w}\right) v^2 \cos\psi \sin\psi \, d\psi \, d\varphi \, \sigma^2 G_{21} \sin\nu \cos\nu \times$$
$$\times d\nu \, d\mu \exp\left(-\frac{\rho}{\lambda_{21}}\right) d\rho \, dF.$$

Molecules were reflected from the element/cell of surface $dF = R^2_0 \sin\theta d\theta d\beta$ in the direction ψ, φ. At the moment of collision the direction of center line is assigned by angles ν, μ relative to the direction of relative speed $\vec{G}_{21} = \vec{V} - \vec{U}_\infty$. Collision occurred at a distance ρ from element/cell dF. The molecules reflected possessed the speeds in the interval $(\vec{v}; \vec{v}+d\vec{v})$, and their quantity is proportional to $\exp(-\rho/\lambda_{21})$, where $\lambda_{21} = \frac{v}{n_\infty \pi\sigma^2 G_{21}}$ — the mean free path of the molecules reflected on the molecules of the incident

flow. From the law of conservation of a number of particles on the surface of sphere it follows that $n_w = 2n_\infty \sqrt{\pi} S_w \cos\theta$.

The collision frequency let us register in the form

$$dN = \pi R_0^2 n_\infty U_\infty f(\theta) f(\psi) f(\nu) f(\rho) f(\varphi) f(\beta) \times$$
$$\times f(V) f(\mu)\, d\theta\, dV\, d\psi\, d\nu\, d\rho\, d\varphi\, d\beta\, d\mu,$$

where

$$f(\theta) = 2\sin\theta\cos\theta;$$
$$f(V) = 2(2RT_w)^{-2}\exp\left(-\frac{V^2}{2RT_w}\right)V^3;$$
$$f(\psi) = 2\sin\psi\cos\psi;$$
$$f(\nu) = 2\sin\nu\cos\nu;\quad f(\rho) = \frac{1}{\lambda_{21}}\exp\left(-\frac{\rho}{\lambda_{21}}\right);$$
$$f(\varphi) = f(\mu) = f(\beta) = \frac{1}{2\pi};$$

moreover for all variable/alternating

$$\int_{x_1} f(x_1)\, dx_1 = 1.$$

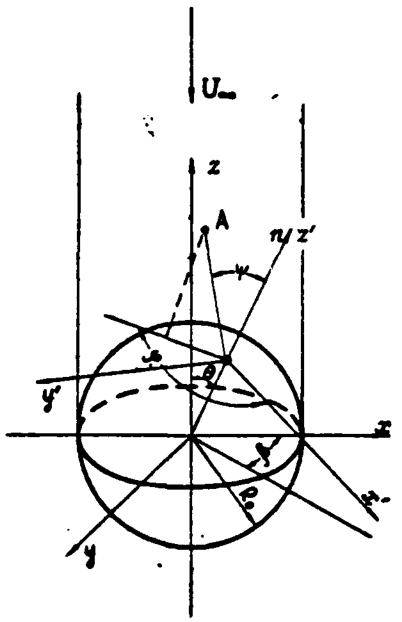

Fig. 15.

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Then the probability of this collision exists

$$\eta=\frac{dN}{N}=f(\theta)f(\psi)f(\nu)f(\rho)f(\varphi)f(\beta)f(\mu)f(V)\,d\theta\, d\psi\, d\nu\, d\rho\, d\varphi\, d\beta\, d\mu\, dV.$$

One drawing let us name the collision, characterized by the random sampling of eight parameters, moreover each parameter was chosen randomly with an appropriate probability density of $f(x_i)$. After the collision was played, were determined the trajectories of molecules after collision, was fixed/recorded the fact of falling of molecule into this point of surface and were memorized the corresponding values of the molecular signs/criteria, yielded by

molecule to the body. Simultaneously it was checked, did not occur collisions at the point of space which is projected/designed along the direction of speed U_∞ to the body surface; if this is so, then at this point of body surface we fix/record the report/event of the loss of the molecular signs/criteria which carried the molecule from infinity. The parameters of each collision are developed according to the following formulas:

$$V=\sqrt{2RT_\infty}\sqrt{-\ln\xi_i\xi_{i+1}};\quad \sin\psi=\sqrt{\xi_{i+2}};$$
$$\sin\nu=\sqrt{\xi_{i+3}};\quad \rho=\left(-2\sqrt{2}\ \mathrm{Kn}_\infty\frac{V}{G_{21}}\right)\ln\xi_{i+4};$$
$$\varphi=2\pi\xi_{i+5};\quad \mu=2\pi\xi_{i+6};\quad \beta=2\pi\xi_{i+7};$$
$$\sin\theta=\sqrt{\xi_{i+8}},$$

where ξ_{i+n} — evenly distributed random numbers [0-1].

After playing collision, we determine the speeds of molecules after collisions V_j and V_{j+1}. Each molecule after collision has the "weight", equal to

$mn_\infty U_\infty \pi R_0^2$ — for the flow of molecules;

$mn_\infty U_\infty \pi R_0^2 U_{nj,j+1}$ — for the flow of normal impulse/momentum/pulse;

$mn_\infty U_\infty \pi R_0^2 U_{xj,j+1}$ — for the pulse stream in direction U_∞;

$mn_\infty \frac{U_\infty}{2} \pi R_0^2 V^2_{j,j+1}$ — for the energy flow.

If collision occurred above any point of body surface, then at this point of surface occurred the loss of the following molecular signs/criteria:

$mn_{\infty}U_{\infty}\pi R_0^2$ — for the flow of molecules;

$mn_{\infty}U_{\infty}\pi R_0^2(\vec{U}_{\infty}\vec{n})$ — for the flow of normal impulse/momentum/pulse;

$mn_{\infty}U_{\infty}\pi R_0^2 U_{\infty}$—for the pulse stream in direction U_{∞};

$mn_{\infty}U_{\infty}\pi R_0^2\frac{U_{\infty}^2}{2}$ — for the energy flow.

If it is necessary to know the distribution of the computed flows from the body surface, it is necessary body surface to decompose into the elements/cells (value of which it is determined from the considerations of accuracy), to count the sums of the flows of the molecular signs/criteria interesting us and to relate them to the area of the element/cell of surface and to a number of drawings K. For the total characteristics necessary to count the sums of the corresponding molecular signs/criteria, which arrive at entire body surface and lost as a result of collisions above the entire body surface relate them to K.

Thus, we compute Π_{+k} and Π_{-k}, where index k indicates the

appropriate molecular sign/criterion.

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A number of drawings K is determined by the assigned accuracy of calculation according to known formulas [16], moreover dispersion is determined in the process of calculation. By the method proposed were determined the aerodynamic characteristics of the whole class of bodies.

1. Sphere. (Fig. 16). Aerodynamic characteristics of the sphere were computed for arbitrary value S_w when $\frac{S_w}{Kn_\infty}<1$ [32]. It was assumed that the reflection of molecules from the surface diffuse and the molecules interact: a) as elastic spheres; b) as pseudo-Maxwellian molecules. Calculations showed that value c_x in the mode/conditions of the first intermolecular collisions is reduced in comparison with its free molecular value approximately/exemplarily to 15% within the framework of the applicability of theory. The results of detailed calculations are given in works [32-34].

Cone (Fig. 16 and 17). In this case the effect of the first intermolecular collisions on different aerodynamic characteristics is different. Allowance to resistance, energy flow and to the value of the pitching moment of "cold" cone when $S_\infty\theta<1$ (with exception of the

thick cones when θ>60°, where θ - half-angle of solution/opening) is negative and does not exceed 10% of value of these aerodynamic characteristics in the free molecular flow in the region of the applicability of the theory of the first collisions. For example, correction due to the collisions for the cone with the significant dimension of h=1 m when $\theta=15°, \alpha=72°, S_\infty=10$ for the height/altitude of 120 km is equal to approximately/exemplarily 7%. Allowance as a result of the collisions to the free molecular value of the lift of "cold" cone in the dependence on the combination of the half-apex angle of the cone and angle of attack can be both positive and by negative and on the average are approximately 50% of $c_{y\,c.m}$. In the "resonance" case when $\alpha \approx \pi/2-\theta$, value Δc_y can be several times more than $c_{y\,c.m}$ (in the given higher example at the height/altitude of 120 km relative value of correction Δc_y it is equal to approximately/exemplarily 150% $c_{y\,c.m}$ and only at the height/altitude of 230 km it composes 10%).

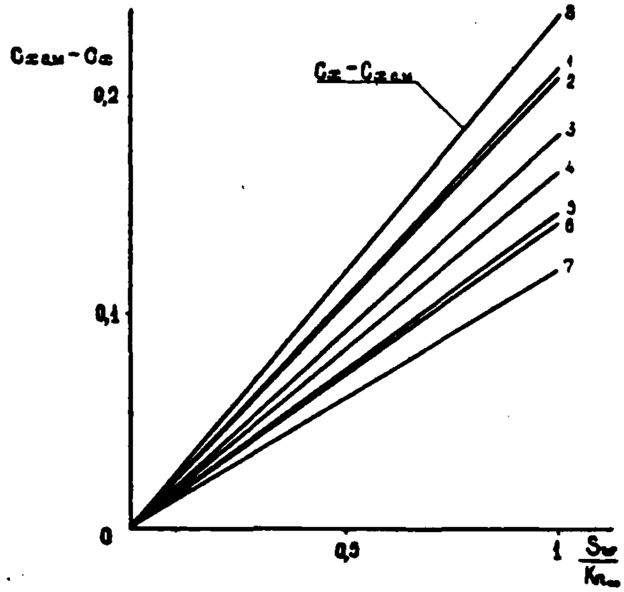

Fig. 16. 1 - circle; 2 - square; 3 - rectangle; 4 - cone, θ=60°; 5 - sphere; 6 - cone, θ=45°; 7 - cone, θ=30°; 8 - circle (along the flow).

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For the thick "cold" cones the allowance due to the collisions to free molecular to the value of pitching moment can be both the positive and negative, and its value can be much more than the free molecular value of pitching moment. In the case of very slender cones when $S_\infty \theta \geqslant 1$ the value of resistance taking into account the first collisions is more than free molecular value. From the given calculations it is possible to draw the following basic conclusions:

- the boundary of free molecular courses for different aerodynamic characteristics of cone lies/rests on different height/altitude and there cannot be determined only on the basis of the Knudsen number; it in many respects depends on the geometry of task, laws of interaction of molecules with each other and with the surface of cone;

- ignorance of the laws of interaction of molecules with the surface (accommodation coefficients) to a high degree affects the determination of lift and pitching moment of cone and to the considerably smaller degree - the determination of the value of resistance and heat flux.

Plate. The results of detailed calculations are published in works [33, 35-40]. Plate is most "convenient" body for obtaining the qualitative laws governing the flow around bodies by the strongly rarefied gas. In work [30] based on the example of plate were determined different types of courses, realized in the case of the flow around the plate, arranged/located at different angles of attack, under different laws of interaction of molecules with each other and with the surface of plate.

The calculations conducted completely confirmed qualitative results [30]. If plate is arranged/located normal to flow [36, 39, 40], then its resistance and energy flow to it in the mode/conditions, close to the free molecular, are reduced within the framework of the applicability of theory approximately/exemplarily to 10%. In the case of the plate, arranged/located in parallel to flow [33, 35, 37, 38], possibly several types of flows depending on the "type" of molecules, law of their interaction with the surface and values of numbers S_∞, S_w and Kn_∞. Thus, in the "cold" case when $S_w \leqslant Kn_\infty$ resistance of plate and energy flow in the flow conditions, close to the free molecular, are more than the free molecular value of maximum by ~10%.

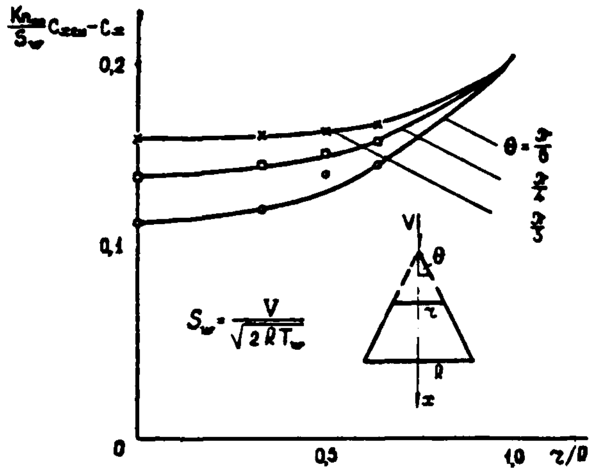

Fig. 17.

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But if are realized the conditions of the so-called molecular boundary layer when $1 \ll Kn_{\infty} \ll S_{\infty} \ll Kn_{\infty}^2$, then within the framework of the applicability of the theory of the first intermolecular collisions value c_x and energy flow can be many times of more than their value in the free molecular flow. Even to the larger degree grows pressure on the surface of plate. For the plate, just as for the thin pointed bodies, high value has a precise knowledge of law of reflection of molecules from the surface, since depending on the law of interaction of molecules with the surface of the value of aerodynamic characteristics they can increase or be reduced by an order. Fig. 16 gives some results of calculations for the plates of various forms.

Skimmer (Fig. 18). Calculations were carried out for the purpose of the determination of flow disturbances at the entrance into the skimmer, the caused by collisions molecules of hypersonic ($S_\infty = \infty$) incident flow with the molecules, reflected from surface [34]. In the investigated modes/conditions the mean free path of molecules in the incident flow was much more than the diameter of the entrance, molecule they were assumed elastic spheres, $S_w = 10$ and 1.57. From the obtained results it is evident that even when $Kn_d=40$ and $S_w=10$ density at the entrance increases by 10% in comparison with its free molecular value. Axial inlet velocity falls, average/mean longitudinal quadratic speed is reduced, all this together undertaken speaks, that at the entrance begin to predominate the oblique collisions. With an increase in the wall temperature the effect of collisions is reduced. Consequently, cooling skimmer can contribute to the decrease of the distortion of flow only in the case of the complete freezing of gas on its surface. The calculations conducted show that even in the case when $Kn_d \gg 1$ and $Kn_D > 1$, intermolecular collisions significantly distort the picture of flow after the skimmer.

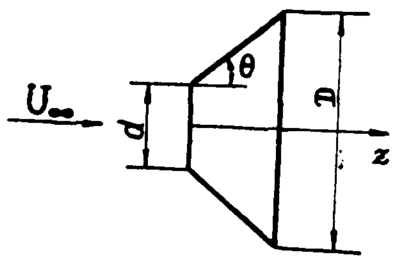

Fig. 18.

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STUDY OF INTERNAL AND EXTERNAL FREE MOLECULAR FLOWS ABOUT AN ARBITRARY GROUP OF COMPLEX BODIES.

M. A. Zakirov.

Are given formulas and universal program comprised on them for calculating of aerodynamic coefficients, local flows through the surfaces and local parameters of gas in the field of flow at the flow of the free molecular flow about the group of complex bodies. Calculations can be carried out under different laws of interaction of molecules with the wall. Body surface is assigned analytically. The velocity vector of the incident flow is arbitrary in the value and in the direction. Program makes it possible to carry out the flow-field analyses of bodies by the flow of light/world and by hypersonic inviscid flow (according to Newton's theory).

ADOPTED DESIGNATIONS.

$V, Vh^{1/2}, h^{-1/2}, T, n, m$ — average/mean and relative gas velocity, the most probable speed, temperature, density and the mass of particles;

Xx_i, Yy_j, Ww_n — coordinate systems, connected with entire body, with the separate surface and with the surface element on surface of (i, j, n=1, 2, 3);

δ_{ji} — unit matrix (j, i=1, 2, 3);

$c_{\pm i}, c_{ri}, m_{\pm i}, m_{ri}$ — coefficients of total aerodynamic forces and moments/torques;

$E_{\pm}, E_r$ — coefficients of total energy flows to the body;

E_k — flux coefficient of the energy through the control surface;

$\left.\begin{matrix}(n_+, n_r), (p_\pm, p_r), \\ (\tau_\pm, \tau_r), (e_\pm, e_r)\end{matrix}\right\}$ — coefficients of the average/mean local particle fluxes, normal and tangential impulses/momenta/pulses and energy through the surface;

$W_{=\lambda}$ – probability of the flight/span of molecule;

p_λ – static pressure;

$\left.\begin{matrix} n_\lambda, V_{j(\lambda)}, T_\lambda, M_{ij(\lambda)}, \\ p_{ij(\lambda)}, E_{j(\lambda)}, q_{j(\lambda)} \end{matrix}\right\}$ – particle density, the average speed, temperature, the tensors of the flux of momentum and stresses/voltages, the flows of complete and thermal energy along the field of flow of gas;

u_λ – particle flux;

$M[X], D[X]$ – mathematical expectation and dispersion;

$N_p (N_{pk})$ – number of particles, played through entire (through the k-th) face of control surface.

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Indices.

∞ - undisturbed flow;

w - condition on the wall;

k - number of the face of control surface;

ν - ν-th surface;

ω, β, γ - local flows through the surface;

λ - local parameters on the field of flow in the vicinity of formal surface S_λ;

n - coefficients in Newton's theory;

f - flow of light/world (photons).

Introduction.

The tasks of the study of free molecular flows appear in connection with the flights of bodies in the free molecular flow and the calculations of flows in the vacuum devices.

The calculations of free molecular flows are performed through two directions: in the first case solve the complicated integral equations of the type of Fredholm the second kind for the function of the distribution of particles [1-6] reflected; in the second case free molecular flow, they simulate by the method of the Monte Carlo [7-12].

The solution of integral equation is obtained for the case of flow of the hypersonic free molecular flow about of the concave sphere and cylinder with the diffuse reflection of particles from surface [2, 13, 14]. Numerical calculations are carried out during the free molecular flow around the infinite cylinder [15] and wedge [16]; cone, hemisphere and cylinder with wings [5, 8]; flat ducts and lattices [17].

In the tasks about the internal flows, the first settings and solutions of which were given in the works of Knudsen, Smoluxovsky

and Clausing (see vast bibliography in the works [1, 5, 6]), are determined the probability of the flight/span of molecules and the density of gas during the flow through the rectangular cylindrical, the conical and wedge channels [17-20]. Is determined also gas density in the vicinity of sphere and cone [21-23].

In the present work is given the calculation procedure by the method of the Monte Carlo of the aerodynamic coefficients of separate surfaces and entire body, and also coefficients of local stresses/voltages in the body surface and local parameters of gas (density, temperature, speed, heat flux, etc.) on the field of internal and external free molecular flows. Calculations can be carried out for arbitrary combination of the complex bodies whose surfaces are assigned analytically. The velocity vector of the incident flow of gas can be arbitrary in the value and the direction. For gaming the reflection of molecules it is possible to apply different models. Employing this procedure it is possible to lead calculations for the bodies in the flow of light/world and according to Newton's theory.

Chapter 1.

UNIVERSAL ALGORITHM OF THE STUDY OF FREE MOLECULAR FLOWS.

The overall diagram of the solution of problem is the following. The geometry of the arbitrarily arranged/located bodies in the space is assigned with the help of set of parameters of surfaces. In accordance with the function of particle distribution of the undisturbed flow is produced the drawing of the random parameters of particles at the "start" from the control surface, which surrounds body. Are developed consecutive collisions and reflections (in accordance with the assigned density) of particles with the body surfaces up to their escape from the control volume. At the moment of the intersection with the molecule of body surface are summarized all necessary flows, throughout which then are calculated the mathematical expectations of the corresponding flows per unit time.

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1. On the analytical method of the assignment to surface of complex body.

Let us consider the complex body whose entire surface can be

represented by the set of the arbitrary parts of the surfaces of the second order. The numbered parts of the surfaces we will call thus: the first surface, the second surface, etc. Let us introduce the system of coordinates Xx_i $(i=1, 2, 3)$ connected with the body.

All surfaces are determined by assignment for each of them the ordered array from the coefficients of the equations of the second order

$$b_{jm}y_jy_m+2b_{j4}y_j+b_{44}=0 \quad (j,\ m=1,\ 2,\ 3), \tag{1.1}$$

written for the convenience relative to the arbitrary system of coordinates Yy_j, oriented relative to system Xx_i by direction cosines a_{ji} between axes x_i and y_j and by coordinates x_{0i} of point Y. In formula (1.1) b_{jm} — tensor (affine tensor); b_{j4} — vector; b_{44} - scalar.

Analytical method includes also the assignment to region D of changing the variable/alternating y_j. During the assignment to D region use Cartesian, polar, cylindrical and spherical coordinates. Then almost for all surfaces, presenting interest from the point of view for the theory and practice, the form D region becomes simplest - rectangular. For the assignment to D region are used: in the Cartesian system of coordinates (y_j) the variable/alternating y_1, y_2, in polar (φ, r, y_3) - φ, r, in the cylindrical (φ, r, y_3) - φ, y_3 and into the spherical (φ, θ, r) - φ, θ. Let us agree on subsequently to

call y_1 and φ external variable/alternating, and y_2, r, y_3 and θ - internal variable/alternating.

Let us do some notes. In the Cartesian and polar coordinate systems D region does not set limitations on values of y_3; therefore for achievement of uniqueness is considered only the part of the surface, which falls into half-space $y_3>0$. By the appropriate selection of the coefficients of equation (1.1) it is possible to achieve entry/incidence into half-space $y_3>0$ of different parts or entire surface. In the case of conical surface it is necessary to throw/reject a small vicinity about the apex/vertex, since the direction of standard/normal at this point is not determined.

Thus, each surface is assigned by set of parameters b_{jm}, $2b_{j4}$, b_{44}, a_{jl}, x_{0i}, β_1, β_2, γ_1, γ_2 and π_*. Here (β_1, β_2), (γ_1, γ_2) - the limits of the rectangular region D on by external and internal variable/alternating; π_* —- sign/criterion, which designates the coordinate system, in which is assigned D region.

The following space is the introduction of the typical classes of surfaces and complex bodies. For example, if are examined only axisymmetric surfaces (circle, cylinder, cone, spherical segment), then a number of assigned parameters about the surfaces substantially is reduced. Complicated surfaces also can be assigned by a smaller

number of parameters; for example, the surface of parallelepiped is determined by the assignment of the coordinates of three apexes/vertexes and height/altitude.

Particle trajectories are calculated relative to axes Xx_i, therefore the equations of all surfaces are converted from one axes Yy_i to the next Xx_i. This is realized into two stages. First is produced the rotation of axes Yy_i so that new axes $Yy'_i \parallel Xx_i$ and equation (1.1) takes the form

$$\left.\begin{array}{c}\psi_{ik} y'_i y'_k + 2\psi_{i4} y'_i + b_{44} = 0; \quad \psi_{ik} = a_{ji} a_{mk} b_{jm}; \\ \psi_{i4} = a_{ji} b_{j4}; \quad y_j = a_{ji} y'_i; \quad y_m = a_{mk} y'_k; \quad i,\ k = 1, 2, 3.\end{array}\right\} \tag{1.2}$$

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Then is realized the parallel shift/shear of axes Yy'_i before the coincidence with axes Xx_i

$$y'_i = x_i - x_{0i}, \tag{1.3}$$

and the equation of surface takes the form

$$\left.\begin{array}{c}a_{ik} x_i x_k + 2a_{i4} x_i + a_{44} = 0; \quad a_{ik} = \psi_{ik}; \\ a_{i4} = \psi_{i4} - \psi_{ik} x_{0k}; \quad a_{44} = x_{0i}(\psi_{ik} x_{0k} - 2\psi_{i4}) + b_{44}.\end{array}\right\} \tag{1.4}$$

2. Selection of the form of control surface.

On control surface (S_0) we will produce gaming the random values

of the components of vector of the particle speed and coordinates of the start of particle. In this case the value of the probability of contact with the body surface of the particle, which starts with S_0,

$$p_n = \frac{N_n}{N_p} \quad (2.1)$$

must be closest possible to one. Here N_n— number of particles fallen on body of all that played N_p on S_0.

If we as S_0 take sphere, then value p_n will be small for the bodies, extended on one or two measurements, but if elliptical cylinder or ellipsoid, then are obtained complicated formulas for the drawing of random variables.

In the present work as the control surface is selected parallelepiped (S_k), since for it value p_n will be sufficient high, and the density function of random variables for faces S_k are simplest.

In the examination of flows within the channels it is profitable to develop flight of particle only through the part of control surface, for example only through one face in plane of which is arranged/located the entrance. After the drawing of the random coordinates of particle on rectangular face S_k is checked their entry/incidence in the section of inlet whose form is arbitrary.

3. On the laws of the distribution of the random parameters of particles.

We will examine Knudsen's gas ($Kn \to \infty$). If about body (final) flows uniform equilibrium (limitless) flow, then the function of the distribution of the incoming particles is equal to Maxwellian

$$f_\infty = n_\infty (h_\infty/\pi)^{3/2} \exp\left[-h_\infty \sum_{i=1}^{i=3} (\xi_i - V_{\infty i})^2\right]; \quad h_\infty = \frac{m}{2kT_\infty}. \qquad (3.1)$$

Here designation conventional (for example, see [1]).

Let us consider now formulas for the drawing of the random components of speed and coordinates of particles on surface S_k.

Preliminary analysis showed that the random components of the particle speed on faces S_k to more simply develop in the Cartesian coordinates. In the cylindrical and spherical coordinates the random variables, which characterize value and direction of the particle speed, are dependent, which strongly complicates drawing. Only when $V_\infty = 0$ are obtained simple formulas for the drawing of the velocity vector of the particle [see formula (4.10)].

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Six faces S_k, which satisfy the equations

$$x_i - x^{\circ}_{1i} = 0,\ k = i;\ \ x_i - x^{\circ}_{2i} = 0,\ k = i + 3;\ \ x^{\circ}_{1i} < x^{\circ}_{2i}, \qquad (3.2)$$

let us number by index k=1, 2, 3, ..., 6. Let us designate through n_{ki} the internal normals to faces S_k.

Expressing the standardized/normalized particle fluxes through faces S_k, we will obtain expressions for the densities of random components ξ_{ki} of particle speed:

components $\vec{\xi}_{ki}$, parallel to standards/normals $\vec{n}_{ki}$,

$$f(\xi'_{ki}) = 2\chi^{-1}(V'_{\infty k})\exp[-(\xi'_{ki} - V'_{\infty k})^2]\,\xi'_{ki}, \qquad (3.3)$$
$$i = k\ (k = 1,\ 2,\ 3),\quad i = k - 3\ (k = 4,\ 5,\ 6),\quad \xi_{ki} \in (0,\ \infty);$$

components ξ_{ki}, parallel to faces S_k,

$$f(\xi'_{ki}) = (\pi)^{-1/2}\exp\{-(\xi'_{ki} - S_{\infty i})^2\}, \qquad (3.4)$$
$$i \neq k\ (k = 1,\ 2,\ 3),\quad i \neq k - 3\ (k = 4,\ 5,\ 6);$$

here

$$V'_{\infty k} = n_{ki} S_{\infty i};\quad S_{\infty i} = v_{\infty i} S_{\infty};\quad v_{\infty i} = V_{\infty i}\,|V_{\infty}|^{-1} = \{-\cos\alpha_0\cos\beta_0,$$
$$\sin\alpha_0\cos\beta_0, -\sin\beta_0\};\quad \chi(x) = \exp(-x^2) + \sqrt{\pi}x(1 + \operatorname{erf} x);$$
$$S_{\infty} = V_{\infty} h_{\infty}^{1/2},\quad \xi'_{ki} = \xi_{ki} h_{\infty}^{1/2};$$

α_0 and β_0 - angles of attack and slip.

Let us note that function (3.3) reaches maximum at the point

$$\xi'_{0k} = 0{,}5\, V'_{\infty k} + (0{,}25\, V'^{2}_{\infty k} + 0{,}5)^{1/2}, \tag{3.5}$$

but function (3.4) - at point $S_{\infty i}$.

Integral laws take the form:

distribution (3.3)

$$R_{ki}(\xi'_{ki}) = \int_{0}^{\xi'_{ki}} f(\xi'_{ki})\, d\xi'_{ki} = 1 + \{\sqrt{\pi}\, V'_{\infty k}[\operatorname{erf}(\xi'_{ki} - V'_{\infty k}) - 1] - \\ - \exp[-(\xi'_{ki} - V'_{\infty k})^2]\}\chi^{-1}(V'_{\infty k}); \tag{3.6}$$

the distribution (3.4)

$$R_{ki}(\xi'_{ki}) = \int_{-\infty}^{\xi'_{ki}} f(\xi'_{ki})\, d\xi'_{ki} = \frac{1}{2}\,[1 + \operatorname{erf}(\xi'_{ki} - S_{\infty i})]. \tag{3.7}$$

For the drawing of the random values of components ξ'^{*}_{ki} it is necessary to find intervals $(\xi'^{a}_{ki}, \xi'^{b}_{ki})$, the probability of the entry/incidence into which of random variables ξ'^{*}_{ki} is close to one.

On the basis of the preliminary estimations for the components of speed ξ_{ki}, parallel to standards/normals n_{ki}, let us consider the following cases:

$$\begin{array}{l} \text{A. } V'_{\infty k} > 3{,}25,\ \xi'^{a}_{ki} = V'_{\infty k} - 3{,}25,\ \xi'^{b}_{ki} = V'_{\infty k} + 3{,}25; \\ \text{B. } 0 \leqslant V'_{\infty k} < 3{,}25,\ \xi'^{a}_{ki} = 0,\ \xi'^{b}_{ki} = V'_{\infty k} + 3{,}25; \\ \text{C. } -4{,}55 < V'_{\infty k} < 0,\ \xi'^{a}_{ki} = 0. \end{array} \quad (3.8)$$

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For case of A, by considering the probability

$$p\,[\xi'^{*}_{ki} < (V'_{\infty k} - 3{,}25)] = R_{ki}(V'_{\infty k} - 3{,}25) = 1 - \\ - \{\sqrt{\pi}\,V'_{\infty k}[1 + \mathrm{erf}\,(3{,}25)] + \exp(-3{,}25^2)\}\,\chi^{-1}(V'_{\infty k}), \quad (3.9)$$

derivative of which

$$\frac{dR_{ki}}{dV'_{\infty k}} = \frac{\sqrt{\pi}\exp(-3{,}25^2)\,(1 + \mathrm{erf}\,(3{,}25))}{\chi^2(V'_{\infty k})}\left[\frac{1 + \mathrm{erf}\,V'_{\infty k}}{1 + \mathrm{erf}\,(3{,}25)} - \frac{\exp(-V'^2_{\infty k})}{\exp(-3{,}25^2)}\right] \quad (3.10)$$

is positive when $V'_{\infty k} \geqslant 3{,}25$, we will obtain that function (3.9) reaches when $V'_{\infty k} \to \infty$ the maximum, equal to

$$\lim_{V'_{\infty k} \to \infty} p \approx \frac{1}{\sqrt{\pi}}\exp(-3{,}25^2)\left(\frac{1}{2 \cdot 3{,}25} - \frac{1}{2^2 \cdot 3{,}25^3} + \ldots\right) \approx 0{,}214 \cdot 10^{-5}. \quad (3.11)$$

It is analogous, for case of A, considering probability $p\,[\xi'^{*}_{ki} > (V'_{\infty k} + 3{,}25)]$, we find that it is not more than value

$$1 - \lim_{V'_{\infty k} \to 3{,}25} p \approx \exp(-3{,}25^2)(\sqrt{\pi}\,3{,}25)^{-1} \approx 0{,}428 \cdot 10^{-5}. \quad (3.12)$$

Thus, for case of A is proved the formula

$$p\,[(V'_{\infty k} - 3{,}25) < \xi'^{*}_{ki} < (V'_{\infty k} + 3{,}25)] > (1 - 10^{-5}). \quad (3.13)$$

Accurately also for case of B we find

$$p\,[0<\xi_{ki}'^{\bullet}<(V_{\infty k}'+3{,}25)]\geqslant(1-2{,}47\cdot 10^{-5}). \quad (3.14)$$

For case of B after numerical calculations according to formula (3.6) was obtained the empirical formula

$$\xi_{ki}'^{b}=1{,}523\,(V_{\infty k}'+4{,}55)^{1/2};\quad (3.15)$$
$$p\,(0<\xi_{ki}'^{\bullet}<\xi_{ki}'^{b})\geqslant(1-10^{-5}).$$

When $V_{\infty k}'\leqslant-4{,}55$ the quantity of molecules, which fall to appropriate face S_k and which constitute from all those falling the portion, approximately equal to

$$S_k\chi(V_{\infty k}')\Big[\sum_{k=1}^{k=6}S_k\chi(V_{\infty k}')\Big]^{-1}\lessgtr 10^{-9}, \quad (3.16)$$

can be disregarded/neglected. Here S_k— area of face k.

Is analogous, for ξ_{ki}', parallel to faces S_k, let us find that

$$p\,[(S_{\infty i}-3{,}25)<\xi_{ki}'^{\bullet}<(S_{\infty i}+3{,}25)]>(1-10^{-5}). \quad (3.17)$$

Since (3.6) and (3.7) are not solved relative to ξ_{ki}', then the drawing of random values $\xi_{ki}'^{\bullet}$ is produced according to Baird's method [12]. In this method in comparison with Neumann's method [25] the condition for the selection of random numbers does not require gaming

the further irregularly distributed random number, designated further by symbol R, since it is formed/shaped on the course of calculations.

The random coordinates of the start of molecules have density function:

$$f(x_{i=k})=\delta(x_i-\overset{\circ}{x}_{1i});\quad f(x_{i\neq k})=(\overset{\circ}{x}_{2i}-\overset{\circ}{x}_{1i})^{-1},\quad k=1,\ 2,\ 3; \qquad (3.18)$$

$$f(x_{i=k-3})=\delta(x_i-\overset{\bullet}{x}_{2i});\quad f(x_{i\neq k-3})=(\overset{\bullet}{x}_{2i}-\overset{\circ}{x}_{1i})^{-1},\quad k=4,\ 5,\ 6; \qquad (3.19)$$

here δ(x) - Dirac's delta-function.

Since the drawing of trajectories is produced relative to coordinates χx_i, then to components ξ'_{ki} of particle speed after drawing according to formula (3.3) for cases of k=4, 5, 6 it is necessary to confer minus sign.

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4. Drawing of random particle trajectories under different laws of reflection of particles from the wall.

Let us designate x_{1i} and x_{ri}— the coordinate of initial and end point of one of the elements/cells of break - particle trajectory, which tests/experiences collisions with the concave surface. With the start with S_k we have

$$\left.\begin{array}{l} x_{1i(i=k)} = \overset{\bullet}{x}_{1i}, \quad x_{1i(i\neq k)} = \overset{\bullet}{x}_{1i} + R_1(\overset{\circ}{x}_{2i} - \overset{\circ}{x}_{1i}); \quad k = 1,\ 2,\ 3; \\ x_{1i(i=k-3)} = \overset{\circ}{x}_{2i}, \quad x_{1i(i\neq k-3)} = \overset{\bullet}{x}_{1i} + R_2(\overset{\circ}{x}_{2i} - \overset{\circ}{x}_{1i}); \quad k = 4,\ 5,\ 6. \end{array}\right\} \tag{4.1}$$

From point x_{1i} the molecule moves over the straight line

$$x_i = x_{1i} + \overset{\circ}{\xi}_{-1i}\, t; \quad \overset{\circ}{\xi}_{-1i} = \xi_{-1i}\left(\sum_{i=1}^{i=3} \xi^2_{-1i}\right)^{-1/2}. \tag{4.2}$$

Index - "in the speeds designates the emitted, "+" arriving flying particle, and superscript" ° "designates the unit vector of vector of velocity. Solving system from equations (1.4) and (4.2), we determine values of t_1 and t_2:

$$t_{1,2} = [-b \pm (b^2 - 4ac)^{1/2}](2a)^{-1}, \tag{4.3}$$

where $a = a_{ik}\overset{\circ}{\xi}_{-1i}\overset{\circ}{\xi}_{-1k}$; $b = 2(a_{ik}x_{1i}\overset{\circ}{\xi}_{-1k} + a_{i4}\overset{\circ}{\xi}_{-1i})$; $c = a_{ik}x_{1i}x_{1k} + 2a_{i4}x_{1i} + \bar{a}_{44}$,

for which straight line (4.2) can intersect surface (1.4).

Due to the final accuracy of arithmetic operations by ETsVM [- digital computer] the coordinates of the collision of molecules with the surface can be computed with the "short round" or the "flight/passage". In order to eliminate the effects of these cases, we will accept, that with

$$(b^2 - 4\ ac) < 0; \quad t_1 < \varepsilon_1, \quad t_2 < \varepsilon_1 \tag{4.4}$$

the molecule does not encounter surface, but with

$$t_1 \geqslant \varepsilon_1, \quad -\infty < t_2 < \infty; \quad t_2 \geqslant \varepsilon_1, \quad -\infty < t_1 < \infty \tag{4.5}$$

is possible the collision of particle with the surface with t_1 or t_2 or when $t_{1,2} \geqslant \epsilon_1$. Calculations show that it is possible to take $\epsilon_1 = 10^{-5}$.

Thus, are found one or two points of intersection of particle with the surface

$$x_{im} = x_{1i} + \overset{\circ}{\xi}_{-1i} t_m, \quad m = 1, 2. \tag{4.6}$$

After this is produced checking the entry/incidence of points x_{im} to the assigned piece of surface, determined by D region, for which it is necessary to calculate coordinates x_{im} in that system, in which is assigned D region. Values $t_1(t_2)$, with which the intersection of surface did not take place or the corresponding points do not fall into D region, are substituted by number $L_1 > L_2$; L_2 is equal to maximum size S_k.

The cycle of this checking is completed for all surfaces (1.4) of body. From the obtained set t is determined t_{min}. If $t_{min} \geqslant L_2$, then particle does not intersect body, otherwise intersects it at the point

$$x_{ri} = x_{1i} + \overset{\circ}{\xi}_{-1i} t_{min}. \tag{4.7}$$

The reflection of particle from point x_{ri} is realized depending on the assigned boundary conditions on the surface.

With the mirror reflection of molecule the speed of reflections of molecule is equal to

$$\xi_{-ri}=\xi_{+ri}-2(\xi_{+ri}n_i)n_i. \qquad (4.8)$$

Here n_i — internal normal to the surface.

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In the case of diffuse reflection from the surface is introduced local system of coordinates Ww_n with beginning $W(x_i)$ and axes w_n such, that cosines c_{ni} of the angles between w_n and x_i are equal to

$$c_{1i}=[\overset{\circ}{\xi}_{+ri}-(\overset{\circ}{\xi}_{+ri}n_i)n_i][1-(\overset{\circ}{\xi}_{+ri}n_i)^2]^{-1/2};\quad c_{2i}=(n_i\times c_{1i});\quad c_{3i}=n_i;$$
$$(\overset{\circ}{\xi}_{+ri}n_i)<0. \qquad (4.9)$$

If $(\overset{\circ}{\xi}_{+ri}n_i)\geqslant 0$, then vectors c_{2i} and c_{3i} vary directions to the opposite ones; if $(\overset{\circ}{\xi}_{+ri}n_i)=\pm 1$ then, accepting $c_{13}=0$ and taking into account that $|c_{1i}|=1$, $(c_{1i}n_i)=0$, we will obtain $c_{11}=-n_2c_{12}/n_1$, $c_{12}=-[1+(n_2/n_1)^2]^{-1/2}$,

The speed of the diffuse reflected particle is developed according to the formulas (see also [11])

$$\left.\begin{aligned}&\xi_{-ri}=\overset{\circ}{\xi}_{-ri}|\xi_{-r}|;\quad \overset{\circ}{\xi}_{-ri}=c_{in}\overset{\circ}{\xi}_{-rn};\quad \overset{\circ}{\xi}_{-rn}=\{\cos\varphi\sin\theta,\sin\varphi\sin\theta,\cos\theta\};\\&\varphi=2\pi R_3;\quad \sin\theta=\sqrt{R_4};\quad |\xi_{-r}|=(-h_r^{-1}\ln(R_5R_6))^{1/2};\\&h_r^{-1}=\alpha_*(h_w)^{-1}+\frac{\xi_{+r}^2(1-\alpha_*)}{2}.\end{aligned}\right\}(4.10)$$

Here $\varkappa_*$ — accommodation coefficient of energy with the mirror-diffused reflection.

With the mirror-diffused reflection each molecule with probability p_* is reflected diffuse, i.e., if $p_*>R_?$, then reflection is diffuse, otherwise it is mirror.

Let us consider law of reflection of molecules, given by Maxwell's function

$$f_r = n_r (h_r/\pi)^{3/2} \exp\left[-h_r \sum_{n=1}^{n=3} (\xi_{rn} - V_{rn})^2\right] \quad (4.11)$$

with five macroparameters n_r, h_r, V_{rn}. Designating the average/mean values of the components of the speed of the molecules reflected in system Ww_n, constructed in accordance with formulas (4.9), through $\bar{\xi}_{rn} = \{\bar{\xi}_{r1}, 0, \bar{\xi}_{r3}\}$, the average/mean value of energy of the molecules (per unit of mass) reflected - through $\bar{\xi}_r^2/2$ and the relative average speed - through $S_{rn} = \{S_{r1}, 0, S_{r3}\} = V_{rn} h_r^{1/2}$, we will obtain

$$\bar{\xi}_{r1} = V_r \sin\theta_r; \quad \bar{\xi}_{r3} = V_r \varphi'/S_r; \quad \bar{\xi}_r^2/2 = \frac{V_r^2}{2S_r^2}[2 + S_r^2 + S_{r3}(\varphi' - S_{r3})];$$
$$\varphi' = S_{r3} + 0{,}5\sqrt{\pi}(1 + \operatorname{erf} S_{r3})\chi^{-1}(S_{r3}); \quad \cos\theta_r = -(n_i V_{ri}^{\bullet}). \quad (4.12)$$

Hence we obtain the transcendental equation

$$\psi=\varphi'^2(2+S_{r2}\varphi')^{-1}-\overline{\xi}_{r3}^2(\overline{\xi}_r^2-\overline{\xi}_{r1}^2)^{-1}. \qquad (4.13)$$

It is evident that this model does not limit the physical picture of phenomenon, since the left side where $0\leqslant\psi\leqslant 1$, does not contradict right. $\overline{\xi}_r^2\geqslant\sum_{n=1}^{n=3}\overline{\xi}_{rn}^2$.

Average/mean values $\overline{\xi}_{rn}$ were determined with $V_\infty\gtrsim 10^6$ cm/s in work [10] in the form

$$\alpha_e=\xi_1^{-2}(\xi_1^2-\overline{\xi}_r^2);\quad \alpha_n=\xi_1^{-1}(\overline{\xi}_{r3}-\xi_{13});\quad \alpha_\tau=\xi_1^{-1}(\xi_{11}-\overline{\xi}_{r1}). \qquad (4.14)$$

Components ξ_{1n} and ξ_{rn} are expressed in system $W\varpi_n$.

From (4.13) and (4.14) we obtain the condition of the solvability

$$(\sin\theta_1-\alpha_\tau)^2+(\alpha_n-\cos\theta_1)^2\leqslant(1-\alpha_e),\quad \cos\theta_1=(n_i\,\xi_{1i}^{\bullet}), \qquad (4.15)$$

i.e., the terminuses of vector (α_τ, α_n) must be placed in upper half of circle with the center at point ($\sin\theta_1$, $\cos\theta_1$) and with radius $(1-\alpha_e)^{1/2}$.

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The sequence of calculations is the following.

1. Are calculated θ_1, α_ε, α_n, α_τ, $\overline{\xi^2_r}$, $\bar{\xi}_{r3}$, $\bar{\xi}_{r1}$ and ψ.

2. Is solved equation (4.13). With $0.04 \leqslant \psi \leqslant 0.9612$ was applied the method of linear interpolation. With $\psi > 0.9612$ it is obtained with error 0.1%

$$S_{r3} = \{[1{,}5 + (16\psi - 13{,}75)^{1/2}][2(1-\psi)]^{-1}\}^{1/2}, \quad (4.16)$$

while with $\psi < 0.04$

$$S_{r3} = -[(1 + (1 - 18\psi)^{1/2})(2\psi)^{-1}]^{1/2}. \quad (4.17)$$

These relationships/ratios are found from asymptotic expansions of function $\psi(S_{r3})$ when $S_{r3} \to \infty$ and $S_{r3} \to -\infty$.

3. It is calculated φ', then

$$S_{r1} = \varphi' \bar{\xi}_{r1}/\bar{\xi}_{r3}; \quad (h_r)^{-1/2} = \bar{\xi}_{r3}/\varphi'; \quad V_r = S_r (h_r)^{-1/2}; \quad S^2_r = S^2_{r1} + S^2_{r3}. \quad (4.18)$$

The drawing of the components of speed ξ_{rn} of particle is produced employing the procedure, presented in Section 3. Then is computed $\xi_{rl} = c_{ln}\xi_{rn}$. It is obvious, in the general case with the multiple reflections of particle from the concave surface coefficients α_ε, α_n and α_τ it is not possible to consider constants. Assuming that the particle, which falls at a high speed to the surface, reduces its energy due to the multiple reflections and it reaches equilibrium with the surface, with which

$$\overline{\xi^2_r} = 2h_w^{-1}; \quad \overline{\xi^2_{r3}} = \frac{\pi}{4} h_w^{-1}; \quad \overline{\xi^2_{r1}} = 0; \quad \psi = \frac{\pi}{8}; \quad \varphi' = \frac{\sqrt{\pi}}{2}, \quad (4.19)$$

we will describe the process of achieving the equilibrium, by the dependences, which give a change in the values, which characterize energy of the particle:

$$\overline{\xi_r^2}\,\xi_1^{-2} = 2h_w^{-1}\,\xi_1^{-2} + \varphi_e[(1-\alpha_e) - 2h_w^{-1}\,\xi_1^{-2}];\quad \bar{\xi}^2_{r3}\,\xi_1^{-2} = \frac{\pi}{4}\,h_w^{-1}\,\xi_1^{-2} + \\ + \varphi_n[(\alpha_n - \cos\theta_1)^2 - \frac{\pi}{4}\,h_w^{-1}\,\xi_1^{-2}];\quad \bar{\xi}^2_{r1}\,\xi_1^{-2} = \varphi_\tau(\sin\theta_1 - \alpha_\tau)^2. \tag{4.20}$$

Coefficients φ_e, φ_n and φ_τ vary from one (with the high energies) to zero (with low energies). Were examined the following cases:

1) coefficients φ_e, φ_n and φ_τ depend on the number of multiple reflections on the exponential dependence

$$\varphi_e = \varphi_n = \varphi_\tau = \exp(aa_1),\quad a<0,\quad a_1 = p - p_0, \tag{4.21}$$

on the linear dependence

$$\varphi_e = \varphi_n = \varphi_\tau = (p_{00} - p)(p_{00} - p_0)^{-1},\quad p_{00} - p_0 \geqslant 1; \tag{4.22}$$

2) coefficients φ_e, φ_n and φ_τ are assigned by the arbitrary monotonic functions of energy of incident particles.

In formulas (4.21), (4.22) p - reference number of the collision of particle; p_0 - number of reflections (inclusively), in which during calculation $\bar{\xi}_{rn}$ and $\overline{\xi_r^2}$ coefficients α_e, α_n and α_τ are assumed to be constants; α<0 - arbitrary coefficient. Reflection with the

number of collision p_{00} (inclusively) in (4.22) becomes diffuse with the complete accommodation. Let us note that assigned dependences α_e, α_n, α_τ, φ_e, φ_n and φ_τ must satisfy the condition of solvability (4.15).

5. Calculation of the total particle fluxes, impulse/momentum/pulse and energy. Calculation of dispersions.

Let us designate the flows from the first collision by index "+", from first reflection "-" and from the second collision and the reflection and so forth to the escape of particle into infinity from point x_{rl} — by index r. Particle fluxes relate to $n_\infty V_\infty$, impulses/momenta/pulses - to $mn_\infty V_\infty^2/2$, energies - to $kmn_\infty V_\infty^3/2$. During the calculation of aerodynamic flux coefficients of forces relate to $mn_\infty \dot{V}_\infty^2 S_M/2$, moments/torques to $-mn_\infty V_\infty^2 S_M d_M/2$. When $V_\infty=0$ instead of V_∞ is used $h_\infty^{-1/2}$

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Mathematical expectations of the aerodynamic force coefficients and moments/torques of the compound:

$$\left.\begin{aligned}
&c_{\pm l}=\pm A\sum_{\mu=1}^{\mu=N_\text{п}}\xi_{\pm 1 l};\quad c_{rl}=A\sum_{\mu=1}^{\mu=N_\text{п}}(\xi_{+2l}-\xi_{-rl});\\
&m_{\pm l}=\pm\frac{A}{d_\text{м}}\sum_{\mu=1}^{\mu=N_\text{п}}(x_{1l}\times\xi_{\pm 1l});\\
&m_{rl}=\frac{A}{d_\text{м}}\sum_{\mu=1}^{\mu=N_\text{п}}[(x_{2l}\times\xi_{+2l})-(x_{rl}\times\xi_{-rl})];\quad A=\frac{2Bp_\text{п}}{V_\infty N_\text{п}S_\text{м}};\\
&B=\frac{0{,}5}{\sqrt{\pi}S_\infty}\sum_{k=1}^{k=6}S_k\chi(V_{\infty k}').
\end{aligned}\right\}\quad(5.1)$$

Here μ - number of the particle, played with S_k and that fallen on body. Total coefficients of complicated body:

$$c_l=c_{+l}+c_{-l}+c_{rl};\quad m_l=m_{+l}+m_{-l}+m_{rl}.\qquad(5.2)$$

Examining the sequence of the random values of the aerodynamic coefficients, obtained according to the results of the drawing of each μ-th particle trajectory, we will obtain for calculating the dispersions the following recursion relations:

$$\left.\begin{aligned}
&M[X]=a_0M_\mu;\quad D[X]=a_0^2D_\mu;\quad M_\mu=[(\mu-1)M_{\mu-1}+Z_\mu]/\mu;\\
&D_\mu=\{[D_{\mu-1}+(M_{\mu-1}-M_\mu)^2](\mu-1)+(Z_\mu-M_\mu)^2\}/\mu;\quad a_0=\frac{2Bp_\text{п}}{b_0V_\infty}.
\end{aligned}\right\}(5.3)$$

Here M and D designate mathematical expectation and dispersion;

$$\begin{aligned}
&Z_\mu=(\xi_{+1l}-\xi_{-rl}),\quad b_0=S_\text{м}\ \text{при}^{(1)}\ X\equiv c_l;\\
&Z_\mu=(x_{1l}\times\xi_{+1l})-(x_{rl}\times\xi_{-rl}),\quad b_0=S_\text{м}d_\text{м}\ \text{при}^{(1)}\ X\equiv m_l.
\end{aligned}$$

Key: (1). with.

The central axis of the system of the forces, applied to the body, is parallel to vector c_i and it passes through the point

$$x_{i0} = -d_u[m_i \times c_i][|m_i|^2|c_i|^2 - (c_i m_i)^2][|c_i|^2|m_i \times c_i|^2]^{-1}, \qquad (5.4)$$

moreover moment with respect to this point

$$m_{i0} = c_i(c_i m_i)|c_i|^{-2}, \quad m_{i0} \| c_i. \qquad (5.5)$$

Flux coefficients of energy to the body:

$$\left.\begin{aligned} E = E_+ + E_- + E_r; \quad E_\pm = \pm A_1 \sum_{\mu=1}^{\mu=N_n} \xi_{\pm 1}^2; \quad E_r = A_1 \sum_{\mu=1}^{\mu=N_n} (\xi_{+2}^2 - \xi_{-r}^2); \\ A_1 = \frac{B p_n}{V_\infty^2 N_n}. \end{aligned}\right\} \qquad (5.6)$$

Flux coefficient of the energy through the control surface

$$E_k = A_1 \sum_{\mu=1}^{\mu=N_p} |\xi_{k\,i}|^2.$$

When $S_\infty \gg 1$ value E_+ is approximately equal to the area of the "shadow" of complicated body for the plane, perpendicular V_∞.

Is calculated also relative value of further collisions $(N_\infty + N_r)N_\infty^{-1}$, where N_∞ and N_r — quantity of all particles, which fall on body from infinity and after the first reflection.

With the diffuse reflection of particles from the concave

surface with the complete accommodation easily is established/installed the dependence of coefficients on temperature T_w of the surface:

$$c_{-i} \sim S_w^{-1},\quad c_{ri} \sim S_w^{-1},\quad E_{-i} \sim S_w^{-2},\quad E_r \sim S_w^{-2},\quad S_w = S_\infty (T_\infty/T_w)^{1/2}. \quad (5.7)$$

Here and throughout symbol "~" designates proportionality.

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6. Calculation of the aerodynamic interaction coefficients of surfaces and bodies.

We will examine the aerodynamic force coefficients and moments/torques, which function on the surface of concave body as a result of multiple collisions of particles with the surface. Indices "+", "-" and r will designate flows from the first collision, from the first reflection and from the multiple collisions of particles with the surface. Aerodynamic force coefficients relate to $mn_\infty V_\infty^2 S_м/2$ moments/torques - to $mn_\infty V_\infty^2 S_м d_м/2$. When $V_\infty = 0$ instead of V_∞ is used $h_\infty^{-1/2}$.

Mathematical expectations of the aerodynamic force coefficients and the moments/torques, which function on ν-th surface of complicated body in body axes Xx_i:

$$\left.\begin{aligned}
&c_{\pm\nu i}=\pm A\sum_{\mu=1}^{\mu=N_{\text{п}}}\xi_{\pm 1\nu i};\quad c_{r\nu i}=A\sum_{\mu=1}^{\mu=N_{\text{п}}}(\xi_{+2\nu i}-\xi_{-2\nu i}+\ldots-\xi_{-r\nu i});\\
&m_{\pm\nu i}=\pm\frac{A}{d_{\text{м}}}\sum_{\mu=1}^{\mu=N_{\text{п}}}(x_{1\,i}\times\xi_{\pm 1\nu i});\\
&m_{r\nu i}=\frac{A}{d_{\text{м}}}\sum_{\mu=1}^{\mu=N_{\text{п}}}[(x_{2\,i}\times\xi_{+2\nu i})-(x_{2\,i}\times\xi_{-2\nu i})+\ldots-(x_{r i}\times\xi_{-r\nu i})];\\
&A=\frac{2Bp_{\text{п}}}{V_\infty N_{\text{п}}S_{\text{м}}};\quad B=\frac{0,5}{\sqrt{\pi}S_\infty}\sum_{k=1}^{k=6}\chi(V'_{\infty k})S_k.
\end{aligned}\right\}\quad(6.1)$$

In these formulas are summarized the impulses/momenta/pulses during the incidence/drop in the particle on ν-th surface with the drawing of all $\mu=1\div N_{\text{п}}$ particle trajectories.

Aerodynamic coefficients of the surface:

$$c_{\nu i}=c_{+\nu i}+c_{-\nu i}+c_{r\nu i};\quad m_{\nu i}=m_{+\nu i}+m_{-\nu i}+m_{r\nu i}.\qquad(6.2)$$

If complex body consists of several separate bodies, then, summarizing coefficients (6.1) for the surfaces of which consists separate body, it is possible to compute the aerodynamic interaction coefficients of the bodies, which fly on certain distance from each other.

7. Calculation of the local particle fluxes, impulse/momentum/pulse and energy through the surface of complex body.

The coefficients of local particle fluxes (n_+ and n_r) we will carry to $n_\infty V_\infty$, normal ($p_\pm$ and p_r) and tangential ($\tau_\pm$ and τ_r) impulses/momenta/pulses - to $mn_\infty V_\infty^2/2$ and energies ($e_\pm$ e_r)-to $mn_\infty V_\infty^3/2$.

For calculating the local flows the surface is divided on the pads ΔS: first is divided the rectangular region D of the assignment to surface on the large number m² of equal rectangles with the help of 2(m-1) straight lines, carried out through each side of rectangle D in parallel to its sides. Let the centers of all areas/sites ΔS have integral coordinates on the external variable/alternating region Dβ=1-m and in terms of the internal variable/alternating γ=1-m and the general/common/total numbering:

$$\omega = (\beta - 1)m + \gamma, \quad \omega \in (1 \div m^2). \tag{7.1}$$

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Each of m² rectangles D region determines on the surface area/site ΔS_ω of the arbitrary form whose area is computed from the formula

$$\Delta S_\omega = \int\limits_{\beta_1+\Delta_\beta(\beta-1)}^{\beta_1+\Delta_\beta\beta} \left[\int\limits_{\gamma_1+\Delta_\gamma(\gamma-1)}^{\gamma_1+\Delta_\gamma\gamma} f(z_\beta z_\gamma)\, dz_\gamma \right] dz_\beta; \quad \Delta_\beta = \frac{\beta_2 - \beta_1}{m}; \quad \Delta_\gamma = \frac{\gamma_2 - \gamma_1}{m}; \tag{7.2}$$

here (β_1, β_2), (γ_1, γ_2) - limits D region. Functions (z_β, z_γ) and the variable/alternating z_β, z_γ during the assignment regions D take the

form:

in Cartesian coordinates: (y_j)

$$\dot{f}(z_\beta, z_\gamma) = -n_3^{-1};\quad z_\beta \equiv y_1;\quad z_\gamma \equiv y_2; \tag{7.3}$$

in the polar coordinates (φ, r, y_3):

$$\dot{f}(z_\beta, z_\gamma) = -rn_3^{-1};\quad z_\beta \equiv \varphi;\quad z_\gamma \equiv r; \tag{7.4}$$

in the cylindrical coordinates (φ, r, y_3)

$$f(z_\beta, z_\gamma) = -r(n_1 \cos\varphi + n_2 \sin\varphi)^{-1};\quad z_\beta \equiv \varphi;\quad z_\gamma \equiv y_2; \tag{7.5}$$

in the spherical coordinates (φ, θ, r)

$$f(z_\beta, z_\gamma) = -\sin\theta r^2 (n_1 \cos\varphi \sin\theta + n_2 \sin\varphi \sin\theta + n_3 \cos\theta)^{-1};$$
$$z_\beta \equiv \varphi;\quad z_\gamma \equiv \theta; \tag{7.6}$$

$$n_j = l_j \left(\sum_{j=1}^{3} l_j^2\right)^{-1/2};\quad l_j = -\partial F(y_j, y_m)/\partial y_j = -(b_{jm} y_m + b_{j4}). \tag{7.7}$$

The components of the unit vector of internal standard/normal n_j, value y_3 in the Cartesian and polar coordinate systems, value r in the cylindrical and spherical coordinates are computed with the help of the equation of the surface

$$F(y_j, y_m) = b_{jm} y_j y_m + b_{j4} y_j + b_{44} = 0,\quad (j, m = 1, 2, 3), \tag{7.8}$$

moreover in the solutions of corresponding square equations before the radicals is taken sign "+".

By the values of the coordinates of the impact point in the particle on the surface are determined coordinates (z_β, z_γ) in D region, through which is located the number

$$\omega = m(\beta - 1) + \gamma, \tag{7.9}$$

where

$$\beta = \text{entier}\,[(z_\beta - \beta_1)\,\Delta_\beta^{-1} + 1],\quad \gamma = \text{entier}\,[(z_\gamma - \gamma_1)\,\Delta_\gamma^{-1} + 1],$$

using the address of area/site ΔS_ω. Here entier (x) indicates the near whole, which does not exceed x.

For each area/site in terms of the value of address ω occurs the accumulation of the corresponding sums from which are computed the flux coefficients:

the normal impulses/momenta/pulses

$$p_{\pm\omega} = A_2 \sum_{\mu=1}^{\mu=N_\Pi} |\xi_{\pm 1\omega i} n_i|;\quad p_{r\omega} = A_2 \sum_{\mu=1}^{\mu=N_\Pi} (|\xi_{+2\omega i} n_i| + |\xi_{-2\omega i} n_i| + \ldots + |\xi_{-r\omega i} n_i|); \tag{7.10}$$

the tangential impulses/momenta/pulses

$$\tau_{\pm\omega} = \pm A_2 \sum_{\mu=1}^{\mu=N_\Pi} (\xi_{\pm 1\omega i} c_{1i});\quad \tau_{r\omega} = A_2 \sum_{\mu=1}^{\mu=N_\Pi} [(\xi_{+2\omega i} c_{1i}) - (\xi_{-2\omega i} c_{1i}) + \ldots - (\xi_{-r\omega i} c_{1i})]; \tag{7.11}$$

the energies

$$e_{\pm\omega} = A_3 \sum_{\mu=1}^{\mu=N_\Pi} \xi^2_{\pm 1\omega};\quad e_{r\omega} = A_3 \sum_{\mu=1}^{\mu=N_\Pi} (\xi^2_{+2\omega} - \xi^2_{-2\omega} + \ldots - \xi^2_{-r\omega}); \tag{7.12}$$

the particles

$$n_{+\omega}=A_4\sum_{\mu=1}^{\mu=N_n}\mu_{1\omega};\quad n_{r\omega}=A_4\sum_{\mu=1}^{\mu=N_n}(\mu_{2\omega}+\mu_{3\omega}+\ldots+\mu_{r\omega});\tag{7.13}$$

$$A_2=\frac{2B\rho_n}{V_\infty N_n\Delta S_\omega};\quad A_3=\frac{B\rho_n}{V_\infty^2 N_n\Delta S_\omega};\quad A_4=\frac{B\rho_n}{N_n\Delta S_\omega};$$

$$c_{1i}=[v_{\infty i}-(v_{\infty i}n_i)n_i][1-(v_{\infty i}n_i)^2]^{-1/2},\quad v_{\infty i}=V_{\infty i}|V_\infty|^{-1}.\tag{7.14}$$

If $(v_{\infty i}n_i)=\pm 1$, then $c_{1i}=\{\sin\alpha_0,\ \cos\alpha_0,\ 0\}$.

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In formulas (7.13) $\mu_{1\omega}=1$ during the incidence/drop the particles on ΔS_ω from infinity, otherwise $\mu_{1\omega}=0$; $\mu_{2\omega}, \mu_{3\omega}, \ldots, \mu_{r\omega}$ are equal to one during the incidence/drop in the particle on ΔS_ω after the first reflection, otherwise they are equal to zero.

In the case of the symmetry of flow can be of interest medium stresses/voltages along the bands, parallel to the sides D region. Designating by the index β averaged stresses over the bands in parallel to side γ of D region, and by index γ the averaged stresses/voltages on the bands, parallel to the side β D region, we will obtain

$$p_{+\beta}=\frac{1}{m}\sum_{\beta;\,\gamma=1}^{\gamma=m}p_{+\omega},\quad p_{+\gamma}=\frac{1}{m}\sum_{\gamma,\,\beta=1}^{\beta=m}p_{+\omega},\ldots\tag{7.15}$$

and medium stresses/voltages on over the entire surface

$$p_{+}=\frac{1}{m^2}\sum_{\omega=1}^{\omega=m^2}p_{+\omega},\ldots.\tag{7.16}$$

Varying in formulas (7.15) and (7.16) p on τ, e and n, and index "+" on "-" and r, we will obtain formulas for all averaged flows.

With the diffuse reflection of particles from the concave surface with the complete accommodation easily is established/installed the dependence of coefficients on temperature $\bar{T}_w$ of the surface:

$$p_{-w} \sim S_w^{-1};\ p_{rw} \sim S_w^{-1};\ \tau_{-w} \sim S_w^{-1};\ \tau_{rw} \sim S_w^{-1};\ e_{-w} \sim S_w^{-2};\ e_{rw} \sim S_w^{-2} \quad (1.17)$$

8. Calculation of the local parameters of the flow of the strongly rarefied gas in the vicinity of compound.

Let us consider the procedure of calculation of the penetration probabilities of the particles through the specific surfaces, and also densities, the average speeds and the temperatures of gas, stress tensors and fluxes of momentum, vectors of complete and thermal energy, mass flow rates and static pressures at arbitrary points in the vicinity of compound.

Let us introduce formally into the examination the flat surface which will serve for fixing of the parameters of gas and will not affect particle trajectory. Index λ will designate the number of this

"formal" surface, S_λ— its area.

We will examine the flows of sign/criterion φ, transferred by the particles through the "formal" surface from the outer side [index "+", $(\xi_{+j}n_j)>0$] and from inside [index "-", $(\xi_{-j}n_j)<0$]. The parameters without the index will relate to entire particle flux. Let f - function of particle distribution in the vicinity of this surface. Let us write formula for the flow of sign/criterion φ through surface S_λ:

$$S_\lambda^{-1}\left[\int_{S_\lambda}\int_{(\xi_{+j}n_j)>0}\varphi f(\xi_{+j}n_j)\,dS_\lambda\,d\xi_j+\int_{S_\lambda}\int_{(\xi_{-j}n_j)<0}\varphi f(\xi_{-j}n_j)\,dS_\lambda\,d\xi_j\right]=$$
$$=\frac{n_\infty BV_\infty}{N_p S_\lambda}\left[\sum_{\mu=1}^{\mu=N_p}\varphi_+-\sum_{\mu=1}^{\mu=N_p}\varphi_-\right]. \qquad (8.1)$$

Here is conducted averaging over surface S_λ, which must be sufficient small.

The penetration probabilities of the particles through the formal surface λ from the external and from inside are equal to $W_{\pm\lambda}=N_{\pm\lambda}N_p^{-1}$. Here $N_{\pm\lambda}$— number of molecules from N_p, that fell on formal surface from the external or from inside.

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The densities (concentration) of particles, averaged over

surface S_λ, through which they pass, and those referred to the particle density on infinity n_∞, are expressed from formula (8.1) when $\varphi=(\xi_{\pm j}n_j)^{-1}$:

$$n'_{\pm\lambda}=n_{\pm\lambda}/n_\infty=\pm B_1 S_\lambda^{-1}\sum_{\mu=1}^{\mu=N_p}(\xi_{\pm j}n_j)^{-1};\quad n'_\lambda=n_\lambda/n_\infty=n'_{+\lambda}+n'_{-\lambda},$$
$$B_1=BV_\infty N_p^{-1}. \tag{8.2}$$

The average/mean mass flow rates of molecules, in reference to $(h_\infty)^{-1/2}$, are obtained from (8.1) when $\varphi=\xi_j(\xi_{\pm j}n_j)^{-1}$:

$$\left.\begin{aligned}
&V'_{\pm j(\lambda)}=V_{\pm j(\lambda)}h_\infty^{1/2}=\pm B_2(S_\lambda n'_{\pm\lambda})^{-1}\sum_{\mu=1}^{\mu=N_p}\xi_{\pm j}(\xi_{\pm j}n_j)^{-1};\\
&V'_{j(\lambda)}=V_{j(\lambda)}h_\infty^{1/2}=B_2(S_\lambda n'_\lambda)^{-1}\sum_{\mu=1}^{\mu=N_p}(\xi_{+j}(\xi_{+j}n_j)^{-1}-\xi_{-j}(\xi_{-j}n_j)^{-1});\\
&B_2=B_1h_\infty^{1/2}.
\end{aligned}\right\} \tag{8.3}$$

Taking into account that the temperature of gas is expressed as mean-kinetic energy of the particles

$$\frac{3}{2}kT=\frac{1}{n}\int m(\vec{\xi}-\vec{V})^2/2\,fd\xi_j=\frac{m}{2n}\int\xi^2fd\xi_j-\frac{mV^2}{2}, \tag{8.4}$$

where n, m - density and the mass of particles, we will obtain from (8.1) when $\varphi=\xi^2(\xi_{\pm j}n_j)^{-1}$

$$T'_{\pm\lambda}=\frac{T_{\pm\lambda}}{T_\infty}=\frac{2}{3}T_{\pm\lambda^*}(n'_{\pm\lambda}S_\lambda)^{-1}-\frac{2}{3}V'^2_{\pm\lambda};$$
$$T'_\lambda=\frac{T_\lambda}{T_\infty}=\frac{2}{3}(T_{+\lambda^*}+T_{-\lambda^*})(n'_\lambda S_\lambda)^{-1}-\frac{2}{3}V'^2_\lambda;\quad T_{\pm\lambda^*}=\pm B_3\sum_{\mu=1}^{\mu=N_p}\xi^2(\xi_{\pm j}n_j)^{-1};$$
$$B_3=B_2h_\infty^{1/2};\quad V'_{\pm\lambda}=|V'_{\pm j(\lambda)}|;\quad V'_\lambda=|V'_{j(\lambda)}|. \tag{8.5}$$

Determining the tensor of the flux of momentum by the expression

$$M'_{\delta j} = M_{\delta j}(mn_\infty h_\infty^{-1})^{-1}; \quad M_{\delta j} = m\int \xi_\delta \xi_j f d\xi_j, \tag{8.6}$$

we will obtain from (8.1) when $\varphi = \xi_\delta \xi_j (\xi_{\pm j} n_j)^{-1}$

$$M'_{\pm\delta j(\lambda)} = \pm B_3 S_\lambda^{-1} \sum_{\mu=1}^{\mu=N_p} \xi_\delta \xi_j (\xi_{\pm j} n_j)^{-1}; \quad M'_{\delta j(\lambda)} = M_{+\delta j(\lambda)} + M_{-\delta j(\lambda)}. \tag{8.7}$$

Determining stress tensor by the expression

$$p'_{\delta j} = p_{\delta j}(mn_\infty h_\infty^{-1})^{-1}; \quad p_{\delta j} = m\int (\xi_\delta - V_\delta)(\xi_j - V_j) f d\xi_j = = m\int \xi_\delta \xi_j f d\xi_j - mnV_\delta V_j, \tag{8.8}$$

we will obtain from (8.1) when $\varphi = \xi_\delta \xi_j (\xi_{\pm j} n_j)^{-1}$

$$p'_{\pm\delta j(\lambda)} = M'_{\pm\delta j(\lambda)} - n'_{\pm\lambda} V'_{\pm\delta(\lambda)} V'_{\pm j(\lambda)}; \quad p'_{\delta j(\lambda)} = M'_{\delta j(\lambda)} - n'_\lambda V'_{\delta(\lambda)} V'_{j(\lambda)}. \tag{8.9}$$

Determining the vector of the flow of total energy by the expression

$$E'_j = E_j\left(\frac{m}{2} n_\infty h_\infty^{-3/2}\right)^{-1}; \quad E_j = \frac{m}{2}\int \xi^2 \xi_j f d\xi_j, \tag{8.10}$$

we will obtain from (8.1) when $\varphi = \xi^2 \xi_j (\xi_{\pm j} n_j)^{-1}$

$$E'_{\pm j(\lambda)} = \pm B_4 S_\lambda^{-1} \sum_{\mu=1}^{\mu=N_p} \xi^2 \xi_{\pm j} (\xi_{\pm j} n_j)^{-1}; \quad E'_{j(\lambda)} = E'_{+j(\lambda)} + E'_{-j(\lambda)}; \quad B_4 = B_3 h_\infty^{1/2}. \tag{8.11}$$

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Determining the vector of thermal energy by the expression

$$q'_j = q_j\left(\frac{m}{2} n_\infty h_\infty^{-3/2}\right)^{-1}; \quad q_j = \frac{m}{2}\int (\vec{\xi} - \vec{V})^2 (\xi_j - V_j) f d\xi_j, \tag{8.12}$$

we will obtain from (3.1)

$$\left.\begin{aligned} q'_{\pm j(\lambda)} &= E'_{\pm j(\lambda)} - 2V'_{\pm\delta(\lambda)}\, p'_{\pm\delta j(\lambda)} - V'_{\pm j(\lambda)}\, T_{\pm\lambda *}\, S_\lambda^{-1}; \\ q'_{j(\lambda)} &= E'_{j(\lambda)} - 2V'_{\delta(\lambda)}\, p'_{\delta j(\lambda)} - V'_{j(\lambda)}\, (T_{+\lambda *} + T_{-\lambda *})\, S_\lambda^{-1}. \end{aligned}\right\} \quad (8.13)$$

Static pressure p_λ

$$p'_\lambda = p_\lambda p_\infty^{-1} = n'_\lambda T'_\lambda, \quad (8.14)$$

but average/mean particle flux u_λ through S_λ

$$u'_\lambda = u_\lambda (m n_\infty h_\infty^{-1/2})^{-1} = n'_\lambda V'_{n\lambda}; \quad (8.15)$$

here $V'_{n\lambda}$ projection V'_λ on the normal to S_λ.

Let us note that the started from the formal area of the particle can for a second time clash with the same surface due to an error in the calculations. So that this could not occur, the coordinates of particle with the start must be displaced by the low value $\epsilon_2 \approx 10^{-4}$ in the direction of particle motion.

9. Calculation of aerodynamic coefficients in the flow of Newton and in the flow of light/world.

Employing the procedure, comprised for calculating the free molecular flows, it is possible to calculate the aerodynamic coefficients of the bodies, which fly in the flows of Newton and

light/world.

The total aerodynamic coefficients of bodies c_{iH}, m_{iH} and the coefficients of the local flows of normal impulse/momentum/pulse $p_{\bullet H}$ in Newton's flow are equal to

$$c_{iH} = (c_{+i} + c_{-i})/2; \quad m_{iH} = (m_{+i} + m_{-i})/2; \tag{9.1}$$

$$p_{\bullet H} = (p_{+\bullet} + p_{-\bullet})/2. \tag{9.2}$$

Entering the right sides of these formulas coefficients $c_{\pm i}$, $m_{\pm i}$ and $p_{\pm\bullet}$ [see formulas (5.1) (7.10) are calculated from the procedure of calculation of free molecular flows under the following conditions: $S_\infty \gg 1$, the falling/incident from infinity particle encounters surface only one time and is reflected mirror.

Sometimes appears the need for calculating the aerodynamic characteristics of bodies in the luminous flux, which proceeds from any point source. The luminous flux consists of the photons, which have energy $\varepsilon_\Phi = h\nu$, mass $m_\Phi = \frac{h\nu}{c_0^2}$, impulse/momentum/pulse $p_\Phi = \frac{h\nu}{c_0}$ and numerical density $n_\Phi = \frac{E_\Phi}{h\nu c_0}$; here h - Planck's constant; c_0, ν - speed and the frequency of light/world; E_Φ — light energy, which falls per unit time per unit of area.

With the drawing of particle-photons necessary to assign $S_\infty \gg 1$; the speed of the falling/incident and reflected particles

are equal to V_∞; the designed aerodynamic characteristics will be related to velocity head

$$q_\Phi = \frac{\rho_\Phi c_0^2}{2} = \frac{E_\Phi}{2c_0}, \quad \rho_\Phi = n_\Phi m_\Phi. \tag{9.3}$$

Let k_1, k_2 and k_3 be equal to the portions of that reflected, absorbed and passing through the surface of the luminous flux, moreover $k_1+k_2+k_3=1$. With the drawing of the reflection of particle-photon from the surface of the probability of its reflection, absorption and passage through the surface are equal to respectively k_1, k_2 and k_3.

We will examine the surface, which does not pass light/world ($k_3=0$) and isolated/insulated, so that the absorbed photons will be again scattered according to "cosine law" (diffuse reflection) with the function of the distribution

$$f_\Phi = \frac{n_\Phi \delta(c - c_0)}{4\pi}. \tag{9.4}$$

Here $\delta(c-c_0)$ - Dirac's delta-function. In this case with probability $p_0=k_2(1-k_1)$ particle-photon will be reflected diffusively and with probability k - it is mirror.

Let us note that the worked out methodology makes it possible to

solve also the problems about the diffusion of light in the arbitrary channels.

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Chapter II.

DESCRIPTION OF UNIVERSAL PROGRAM.

The program, given in appendix 1, is comprised in accordance with the algorithm, described in Chapter I. Turnings to IS-2, to the standard programs (SP) for calculating the functions ln(x), exp(x), sin(x), arcsin(x), arctg (x), erf(x), to SP of the multiplication of matrix/die by the vector, the multiplication of matrices/dies and to SP of the group translation/conversion into the binary system from the decimal (10→2) of the array of numbers are written in accordance with [26]. Remaining turnings to IS-2 are given in Table 1 and are isolated in the program with feature to the left.

Table 1.

Номер СП (1)	Наименование СП (2)	Вторая строка * обращения к СП (3)					Примечания (4)
0041	Печать массива чисел от a до b с переводом из 2→10 (5)	$\pi_1 0 \pi_2$	52	a	0041	b	Содержимое ячеек a—b не портится (6)
0150	Линейная интерполяция функций одной переменной (7)	000 $\pi_1 0 \pi_3$	00 75	$\langle n \rangle$ $\langle x \rangle$	0150 $\langle f(x_0) \rangle$	$\langle x_0 \rangle$ $\langle f(x) \rangle$	n — число узлов интерполяции без одного; x_0, $f(x_0)$ — аргумент и функция в первом узле интерполяции; (8) x — текущее значение аргумента (9)
0122	Вычисление двойного интеграла методом (10) Симпсона (11)	000 000 000 000	00 00 00 00	$\langle a \rangle$ $\langle \pm\varepsilon_1 \rangle$ $\langle \pm\varepsilon_2 \rangle$ $\langle c(x) \rangle$	0122 γ σ $\langle f(x, y) \rangle$	$\langle b \rangle$ $\gamma+m$ $\sigma+r$ $\langle x \rangle$	$I=\int_a^b F(x)\,dx,\ F(x)=\int_{c(x)}^{d(x)} f(x,y)\,dy;$ (12) аргументы x и y берутся из $\langle x \rangle$ и $\langle x \rangle+1$; в ячейках $\gamma \div \gamma+m-1$ счет $c(x)$ и $d(x)$, причем $c(x) \rightarrow \langle c(x) \rangle$, а $d(x) \rightarrow \langle c(x) \rangle+1$; в ячейках $\sigma \div \sigma+r-1$ счет $f(x, y)$; $\gamma+m$ и $\sigma+r$ — пустые ячейки; погрешности $\pm\varepsilon_1$ и $\pm\varepsilon_2$ вычисления I и $F(x)$ абсолютные, когда знак (—), и относительные, когда знак (÷); значение I в ячейке 0001

Key: (1). Number. (2). Designation. (3). Second row [1] of turning to SP.

FOOTNOTE [1]. The first row, which is located in nucleus x-1, takes the form 016 x 7501 7610; <x> - cell in which is located number x. ENDFOOTNOTE.

(4). Notes. (5). Press/printing array of numbers from a to b with translation/conversion from 2→10. (6). Contents of nuclei a-b does

not spoil. (7). Linear interpolation of functions of one variable/alternating. (8). number of interpolation points without one; argument and function in first interpolation point. (9). instantaneous value of argument. (10). Calculation of double integral by method. (11). Simpson. (12). argument x and y they are taken from <x> and <x>+1; in nuclei $\gamma-\gamma+m-1$ calculation c(x) and d(x), moreover c(x)⟶ <c(x)>, and (x)⟶ <c(x)>+1; in nuclei $\sigma-\sigma+r-1$ calculation f(x, y); $\gamma+m$ and $\sigma+r$ - empty nuclei; error $\pm\epsilon_1$ and$\pm\epsilon_2$ calculation I and F(x) absolute, when sign (-), and relative, when sign (+); value I in nucleus 0001.

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I. Block I(0) for calculating of total aerodynamic coefficients and local particle fluxes, impulse/momentum/pulse and energy.

This block, which occupies nuclei 0001-6763, is basic the work of all remaining blocks II-IX it occurs with block I(0).

During calculations with block the I (0) reflection of molecules is mirror-diffused, moreover the accommodation coefficient of energy is received as constant. For the calculations with the reflection of molecules according to the law (4.11) are used blocks II and III.

Into the initial information of the version of calculation enters the information about the surfaces of combination of which consists entire/all surface of the compound; the signs/criteria of surfaces, calculation of local flows; the sign/criterion of the mirror-diffused reflection of molecules from the wall (into nucleus 0332 are sent zero); number $\dot{N}_{p}$, more than which there cannot be the number of reflections of molecule from the concave surface of compound with the drawing of one trajectory of molecule; the angles of attack α_0 and slip β_0 (α_0 and β_0 are assigned in degrees); parameter H; the accommodation coefficient of energy α_*; the portion of diffuse reflecting molecules p_0; area and the diameter of midsection $S_м$ and $d_м$; the coordinate of the first x'_{Ti} and the second x''_{Ti} of the points at which it can be placed the center of gravity; the coordinate of the faces of parallelepiped (control surface) $\dot{x}_{1i}$ and $\dot{x}_{2i}(\dot{x}_{1i}<\dot{x}_{2i})$; L_1 and L_2; T_w; number N_{1p}, N_{2p}, N_{3p} and N_{4p}, controlling the readout of calculation. Are assigned also numbers n(P), $n(\alpha_0)$, $n(\beta_0)$, n(H) and $n(\alpha_*)$, the designating quantities of surfaces, angles α_0, β_0, H and α_*. Addresses for the introduction/input of the parameters enumerated above are indicated into block I(O).

Information about each surface is designed in the form of the array of 30 numbers in the sequence, indicated in Table 2.

In this table ν - the number of surface; a=1, if surface is flat/plane, otherwise of a=0, b=0 in the absence of the recording of local flows over the surface ν, otherwise of b=-1 during the calculation of local flows according to inside of surface and b=+1 over the external surface. The recording of local flows can be produced only for one surface. With the work of program with the recording of local flows into nucleus 0330 is sent a number one, otherwise - zero. If limits β_1, β_2, γ_1 and γ_2 D region designate angles, then they are assigned in the radians.

Table 2.

№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)
1	ν	11	a_{13}	21	β_1
2	b_{11}	12	a_{21}	22	β_2
3	b_{22}	13	a_{22}	23	γ_1
4	b_{33}	14	a_{23}	24	γ_2
5	$2b_{14}$	15	a_{31}	25	a
6	$2b_{24}$	16	a_{32}	26	b
7	$2b_{34}$	17	a_{33}	27	0
8	b_{44}	18	x_{01}	28	0
9	a_{11}	19	x_{02}	29	0
10	a_{12}	20	x_{03}	30	0

Key: (1). position. (2). Parameter.

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The information comprised in accordance with Table 2 about all surfaces is introduced into nuclei 0420-1415 (0420-0455 about surface of 1, 0456-0513 about surface of 2, etc.). In all it is possible to introduce information about 17 surfaces (nucleus 0420-1415).

For the designation of the system of coordinates of the assignment of limits β_1, β_2, γ_1 and γ_2 the rectangular region D each surface is accompanied by the indicative code (Table 3). The codes are joined into the array by way of the location of surfaces in

nuclei (0420-1415) and are introduced into nuclei 5201-5221.

Let us note that during the assignment to D region in the Cartesian and polar coordinates it is necessary, in order to for all points of surface $y_3>0$. In the case of cone it is necessary to reject a small vicinity about the apex/vertex. According to calculation data the linear dimensions of this vicinity must be not less than 10^{-8} (for machine M-20), otherwise can occur the stop of machine.

Calculation according to the program can be produced for certain limited quantity of the parameters: $\alpha_0(12)$, $\beta_0(12)$, H(3) and α_* (3). Are here in the brackets indicated maximum quantities of corresponding parameters. During the calculation occurs the consecutive sorting/excess of all combinations of the values of these parameters: first is sorted out every α_0, then β_0, H and α_*. Numbers n(P), $n(\alpha_0)$, $n(\beta_0)$, n(H) and $n(\alpha_*)$, equal to a number of assigned surfaces α_0, β_0 H and α_*, are introduced by the octal codes with the second address into the nuclei (Table 4).

During the calculation according to the value of parameter H with the help of linear interpolation are computed values V_∞, of the average speed of molecules $\overline{V}$ and T_∞. The interpolation points H_0 and value V_∞, $\overline{V}$ and T_∞ in them are assigned in the nuclei, indicated in block 1(0) (see numerical information). Number N_{r*} is introduced by

the octal code with the second address into nucleus 6615.

The drawing of particle trajectories through all faces S_k is produced by "portions" N_{1p}. A maximum quantity of developed particle trajectories is equal to N_{2p}. Printout of total aerodynamic coefficients is produced periodically after the drawing of next "portion" of trajectories $N_{3p} = k_3 N_{1p}$ (k_3=1, 2, 3 ...), and the coefficients of local flows - after the drawing of "portions" of trajectories $N_{4p} = k_4 N_{1p}$ (k_4=1, 2, 3, ...). Number N_{2p} must be integral multiple of numbers N_{3p} and N_{4p}. Numbers $N_{1p} \div N_{4p}$ are sent into nuclei N_{1p} — 0253, N_{2p} — 0254, N_{3p} — 0256 and N_{4p} — 0333.

Let us note that the values of some parameters (N_{r*}, H_0, V_∞, $\overline{V}$, T_∞, T_w, L_1, L_2) are given in block 1(0).

The described initial information is introduced into the memory of machine with block 1(0) in the following sequence: is introduced block 1(0) with the previously specific and pierced on the latter/last punch card check sum (KS); after the comparison of KS of block I control automatically is transmitted to the first nucleus; on the command/crew, which is located in the fifth nucleus, is produced the input of initial information and begins the calculation of problem from nucleus 0006.

Table 3.

Система координат (1)	Код (2)
Декартовая (3)	0 00 0000 0000 0000
Полярная (4)	0 00 0001 0000 0000
Цилиндрическая (5)	0 00 0000 0001 0000
Сферическая (6)	0 00 0000 0000 0001

Key: (1). Coordinate system. (2). Code. (3). Cartesian. (4). Polar. (5). Cylindrical. (6). Spherical.

Table 4.

Адрес (1)	Код (2)				
6616	0	00	0000	$n(\Pi)$	0000
6617	0	00	0000	$n(\alpha_0)$	0000
6620	0	00	0000	$n(\beta_0)$	0000
6621	0	00	0000	$n(H)$	0000
6622	0	00	0000	$n(a_*)$	0000

Key: (1). Address. (2). Code.

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Calculations according to the program are produced in the following sequence (in the brackets are given the numbers of the

nuclei of program):

1) the exchange between MOZU [core storage] MB-1 and MB-2, the press/printing the check sum of version (0006-0063);

2) the expansion of operating field (RP) IS-2 (1500-1501);

3) the translation/conversion of the array of numbers of initial information from the decimal system into the binary (1502-1503);

4) printout of initial information (2507-2512);

5) the recalculation of the coefficients of the equations of all surfaces upon transfer from one axes Yy_j to the next Xx_i (6015-6111);

6) calculation and printout of the values of areas/sites ΔS_{∞}, if contents of nucleus 0330 is equal to 1.0 (5327-5712);

7) the calculation of values S_k, α_0, β_0, H, α_*, $v_{\infty i}$, V_∞, $\overline{V}$, T_∞, S_x, h_∞, h_w, B, $2\chi^{-1}(\dot{V}_{\infty k})$, $N_{pk} N_p^{-1}$, $f_{max}^{-1}(\xi'_{0k})$, ξ'^{a}_{ki}, ξ'^{b}_{ki} (1514-1530, 4010-4266, 4610-4653, 6507-6513, 1541);

8) the drawing of the random speeds and coordinates of particles

with the start from faces S_k (1541-1753, 2005-2022);

9) the program of the drawing of the pseudorandom evenly distributed numbers R_1-R_{10} in interval of 0-1 (6676-6704), of constant to this block (6713-6750);

10) the calculation of the collision of particle with the surface of compound (2030-2536);

11) the calculation of the components of internal normal n_i to the surface at the impact point in the particle and value $\xi_{+ri}n_i$ (2537-2577);

12) the calculation of the components of particle speed with diffuse reflection (2603-2633, 3425-3434, 3151-3166, 2634-2654, 1505-1513, 2655-2660, 3435-3440), with mirror reflection (2661-2673, 6237-6241) and with the reflection according to the law (4.11) (6320-6342, 2622-2634, 6343-6463, 6165-6207, 6465-6506, 6140-6160, 1506-1513, 2655-2660, 3435-3440);

13) the calculation of total flows (2674, 3037, 6271-6317, 2676-2715, 3066-3104);

14) the calculation of local flows (2717-3036, 6161-6164);

15) calculations before the printout of total aerodynamic coefficients (1754-1771, 3112, 6530-6535, 3113-3124, 3145-3150, 6536-6542, 4272-4306, 4667-4777, 4314-4433, 5000-5036, 4434-4450, 5037-5060, 4451, 4520-4545);

16) the command/crew of printout of total aerodynamic coefficients (4546-4547);

17) calculations before the printout of the coefficients of local flows (the same commands/crews as in p. 15 with the addition of commands/crews in nuclei 3124-3144, 3577-3631, 3057-3062, 6562-6607);

18) the command/crew of printout of the coefficients of local flows (3615-3616, 3627-3630, 6573-6574);

19) the sorting/excess of particles N_{2p} (4550-4554, 4654-4655);

20) sorting/excess α_0 β_0 H and α_* (4655-4633, 4555-4567, 4452-4475, 3340);

21) the restoration/reduction of program and the introduction of the new version of calculation (3340, 3145-3147, 4571-4577,

0066-0076, 0006).

Let us note that during the transfer of control to nucleus 3340 at any moment of calculation occurs the restoration/reduction of program and the introduction of new version.

To monitor the correctness of the calculation of problem is possible on the printouts of initial information (2507-2512) from nuclei 0260-0346 and 0420-0646, and also by tracking after nucleus 3521, in which occurs the accumulation of number N_p of the played trajectories, and by nucleus 3550, in which occurs a cyclic increase in the number of multiple reflections of particle from the concave surface in the developed trajectory.

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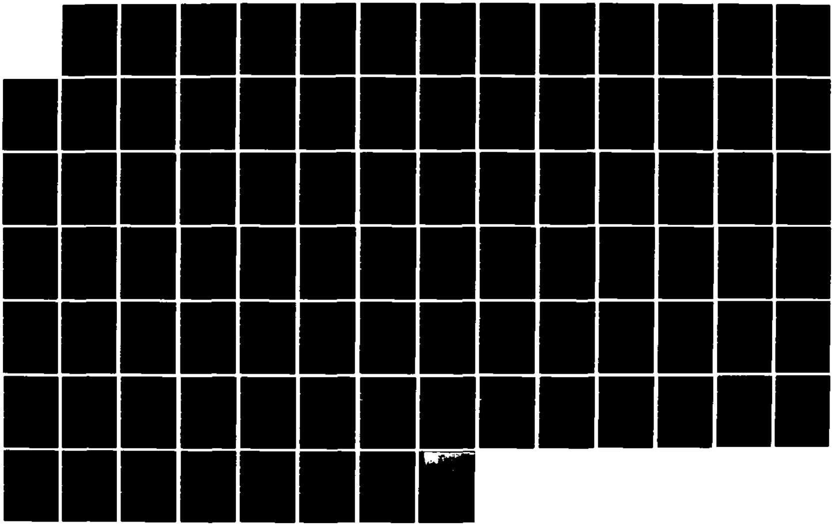
During the calculation of areas/sites ΔS_ω varies the contents of nucleus 5672. To the press/printing areas/sites ΔS_ω are put out by one array (5704-5705) in the sequence, which corresponds to numbering $\omega=(\beta-1)\,m+\gamma$.

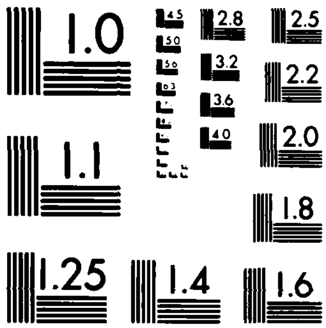
In the program, the number $m=10$, $\omega\in(0-100)$, $\beta\in(0-10)$, $\gamma\in(0-10)$.
The accuracy of calculation ΔS_ω is equal to 0.0001. The check of the correctness of the operation of program and machine can be also produced with calculation for the standard version.

Printout of total aerodynamic coefficients is produced by one

AD-A132 689 DYNAMICS OF RAREFIED GAS AND MOLECULAR GAS DYNAMICS(U) 3/3
FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH
25 AUG 83 FTD-ID(RS)T-0673-83

UNCLASSIFIED F/G 20/4 NL




1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

array (4546-4547); the order of the location of the parameters in the array is given in Table 5.

In the printed array of the group of the parameters are isolated with the help of conditional number П, of equal to —"—+00999999999, and with the help of index "—" in the 45th digit of the binary code of the number (numbers of these numbers in Table 5 are isolated with prime). Aerodynamic coefficients in the drag axes are isolated with index "°", and moment coefficients relative to points $x'_{\tau i}$ and $x''_{\tau i}$— by index "τi" in accordance with one and two primes.

The coefficients of local flows are put out to press/printing 34 by arrays of numbers (Table 6). Arrays 1-11 give the coefficients of the average/mean local flows through areas/sites $\Delta S_{\bullet}$. Array 12 consists of 11 numbers $p'_+, \tau'_+, e'_+, n'_+, p'_r, \tau'_r, e'_r, n'_r, p'_-, \tau'_-, e'_-$. With the help of the parameters, which are contained in arrays 12-34, easily are expressed the coefficients of average/mean flows along the sides β and γ of the rectangular region D

$$p_{+\beta}=\frac{p'_{+\beta}}{10};\ p_{+\gamma}=\frac{p'_{+\gamma}}{10},\ldots \tag{1.1}$$

and average/mean flows in the entire surface

$$p_{+}=\frac{p'_{+}}{100}. \tag{1.2}$$

Varying in formulas (1.1) and (1.2) p on τ, e and n, and index „+" to „−" and r, we will obtain formulas for all averaged flows. In the arrays 1-11 numbers are divided into the groups (by 10 numbers in the group) with the help of index „−" in the 45th digit of the binary code of a number.

2. Blocks II(M) and III(M) for the drawing of the reflection of particles from the surface according to the law (4.11).

Basic part of the program for the simulation of reflection

Table 5.

№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)
1'	α_0	26'		51'	П	76		101		126	
2	β_0	27	c_i	52'		77'		102'		127'	П
3	H	28		53	x_{i0}	78	c_{-i}	103	$c^{\circ}_{+i}+c^{\bullet}_{-i}$	128	
4	S_x	29'		54		79		104		129	$D[c_i]$
5	S_∞	30	m_i	55'		80		105		130	
6	V_x	31		56	m_{i0}	81	m_{-i}	106	$m^{\circ}_{+i}+m^{\bullet}_{-i}$	131	
7	T_x	32'		57		82		107		132	$D[m_i]$
8	T_∞	33	$m'_{i\,т}$	58'	П	83'		108'		133	
9'	α_*	34		59'		84	c_{ri}	109	c°_{-i}	134'	П
10	p_0	35'		60	c_{+i}	85		110		135	
11	B	36	$m''_{i\,т}$	61		86		111		136	$\sqrt{D[c_i]}$
12	N_p	37		62		87	m_{ri}	112	m_{-i}	137	
13	$N_x - N_r$	38'	П	63	m_{+i}	88		113		138	
14	N_r	39'		64		89'	П	114'		139	$\sqrt{D[m_i]}$
15	N_r	40	c°_i	65'		90'		115	$c^{\bullet}_{ri}$	140	
16	$1+N_r/N_x$	41		66	$c_{-i}+c_{ri}$	91	$c^{\bullet}_{+i}$	116		141'	П
17'	E_+	42'		67		92		117		142	
18	E_-	43	$m^{\bullet}_i$	68		93		118	$m^{\bullet}_{ri}$	143	$3\sqrt{D[c_i]}$
19	E_r	44		69	$m_{-i}+m_{ri}$	94	m°_{+i}	119		144	
20	$E_+ + E_-$	45'		70		95		120'	П	145	
21	$E_+ + E_- + E_r$	46	$m^{\bullet\prime}_{i\,т}$	71'		96'		121		146	$3\sqrt{[Dm_i]}$
22	$E_- + E_r$	47		72	$c_{+i}+c_{-i}$	97	$c^{\bullet}_{-i}+c^{\circ}_{ri}$	122	$[M c_i]$	147	
23	E_k	48'		73		98		123			
24	0	49	$m^{\bullet\bullet}_{i\,т}$	74		99	$m^{\bullet}_{-i}+m^{\circ}_{ri}$	124			
25'	П	50		75	$m_{+i}+m_{-i}$	100		125	$M[m_i]$		

Key: (1). No. of position. (2). Parameter.

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according to the law (4.11) is contained in block I(0). The misplaced part is designed by blocks II(M) and III(M). With blocks II(M) and III(M) is introduced also initial information - value of the accommodation coefficients α_e, α_n, α_τ, of number a, p_0-1, $p_{00}-p_0$, function φ_e, φ_n, φ_τ, and also the codes into nuclei 5222-5242. In nucleus 0332 is introduced the number, equal to one.

Table 6.

Номер массива 1	Массив 2	Количество чисел 3	Номер массива 1	Массив 2	Количество чисел 3
1	$p_{+\infty}$	100	18	$\tau'_{r\beta}$	10
2	$\tau_{+\infty}$	100	19	$e'_{r\beta}$	10
3	$e_{+\infty}$	100	20	$n'_{r\beta}$	10
4	$n_{+\infty}$	100	21	$p'_{-\beta}$	10
5	$p_{r\infty}$	100	22	$\tau'_{-\beta}$	10
6	$\tau_{r\infty}$	100	23	$e'_{-\beta}$	10
7	$e_{r\infty}$	100	24	$p'_{+\gamma}$	10
8	$n_{r\infty}$	100	25	$\tau'_{+\gamma}$	10
9	$p_{-\infty}$	100	26	$e'_{+\gamma}$	10
10	$\tau_{-\infty}$	100	27	$n'_{+\gamma}$	10
11	$e_{-\infty}$	100	28	$p'_{r\gamma}$	10
12	$p'_{+}, \tau'_{+}, \ldots$	11	29	$\tau'_{r\gamma}$	10
13	$p'_{+\beta}$	10	30	$e'_{r\gamma}$	10
14	$\tau'_{+\beta}$	10	31	$n'_{r\gamma}$	10
15	$e'_{+\beta}$	10	32	$p'_{-\gamma}$	10
16	$n'_{+\beta}$	10	33	$\tau'_{-\gamma}$	10
17	$p'_{r\beta}$	10	34	$e'_{-\gamma}$	10

Key: (1). Number of array. (2). Array. (3). Quantity of numbers.

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Let the accommodation coefficients for each surface be determined and dependences on the angle θ_1 (angle between vectors of the speed of the falling/incident molecule and vector of internal normal to the surface). In the program are provided the nuclei for dispatching six functions $\alpha_{e1,2}=f(\theta_1)$, $\alpha_{n1,2}=f(\theta_1)$ and $\alpha_{\tau 1,2}=f(\theta_1)$. The values of these functions at points θ_1=0; 15°; 30°; 45°; 60°; 75°; 90° are sent into nuclei 0134-0205 [see the numerical information of block 1(0)]. For each surface is comprised also the special code whose first address is the number of the first nucleus of dependence $\alpha_e=f(\theta_1)$ (for this surface), the second address - number of the first nucleus of dependence $\alpha_n=f(\theta_1)$, the third address - number of the first nucleus of dependence $\alpha_\tau=f(\theta_1)$. All these codes are joined into the array and are introduced into nuclei 5222-5242 (into 5222 - for surface of 1, into 5223 - for surface of 2, etc.). In the given program values α_e, α_n, α_τ [see the numerical information of block I(0)] are undertaken from [10].

With block II are introduced numbers (p_0-1) (1420), a<0 (0313) in the implementation of dependence (4.21) and (p_0-1) (1420), (p_{00}-p_0):$\gg 1$ (0313) in the implementation of dependence (4.22). Are

here in the brackets indicated the numbers of nuclei.

Block II+III makes it possible to simulate arbitrary monotonic dependences φ_{ε}, φ_{n}, φ_{τ} on the square of speed ξ^2_{+r} of incident particle. With block II+III are sent the values of interpolation points ξ^2_{+r} into nuclei 6764-6774 and respectively the value of functions in them φ_{ε} (6775-7005), φ_{n} (7006-7016), φ_{τ} (7017-7027).

3. Block IV (P) for calculating the coefficients of the aerodynamic forces, which function on each surface.

Printout of the aerodynamic coefficients of surfaces is produced periodically after the drawing of next "portion" of trajectories N_{4p} (see the description of block I). The coefficients of surfaces are put out to the press/printing by the arrays each of which relates to the specific surface with respect to the location of information about the surfaces in nuclei 0420-1415. Table 7 gives the order of the location of the aerodynamic coefficients of surface in the array.

After printout of the coefficients of all surfaces is produced the printout of total coefficients just as in block I.

4. Block V(V)for the simulation of free molecular flow in the concave cavity.

In the case of concave cavity for studying the internal flows it suffices to develop random particle trajectories on the plane of entrance.

Table 7.

№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)	№ позиции (1)	Параметр (2)
1		7		13		19	
2	c_{+vi}	8	c_{-vi}	14	$c_{\gamma vi}$	20	c_{vi}
3		9		15		21	
4		10		16		22	
5	m_{+vi}	11	m_{-vi}	17	$m_{\gamma vi}$	23	m_{vi}
6		12		18		24	

Key: (1). position. (2). Parameter.

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Concave surface is oriented so that the plane of entrance would coincide with the plane of the fourth face of control surface (k=4), moreover the center of the area of the figure of entrance to the center of the fourth face of control surface they must coincide. Depending on the form of the duct/contour of entrance into nucleus 3344 is introduced the special code, indicated in Table 8.

In the case of the rectangular form of entrance its duct/contour must coincide with the duct/contour of the fourth face of control surface, in the case of the elliptic form of the entrance, inscribed into the duct/contour of the fourth face, into nuclei 0243 and 0244

are sent the sizes/dimensions of the semi-axes of ellipse, parallel with respect to axes x_2 and x_3.

With the printout of total coefficients are printed parameters 1-120 (see Table 5), then they are printed (4551-4552) two numbers: number of particle trajectories, played from the fourth face and which did not fall on the entrance into the concave cavity and which fell on entrance. Printout of the coefficients of local flows is produced just as in block I.

5. Block VI (K) for the calculations of the local parameters according to the field of internal and external flows.

With the work with this block the drawing can be produced over the entire surface of parallelepiped - control surface or only on the fourth face of control surface (entrance into the internal cavity, see block V). In the first case into nucleus 3344 are sent zero, in the second case into nuclei 3344, 0243 and 0244 is sent the information according to the description of block V.

Information about the "formal" surfaces whose number must not exceed 16, is introduced into nuclei 0420-1415 just as for the usual surfaces, the order of the location of "formal" and usual surfaces not playing role. In the sequence ν=1, 2, 3 ...of all surfaces there is the numeration λ=1,2,3 ... of the formal surfaces. In nuclei

3242-3261 are introduced the sizes/dimensions of areas S_λ of all "formal" surfaces (into the nucleus 3242-S_1, in 3243-S_2 and so forth). In nuclei 5222-5242 with the information described in blocks II and II+ III, is introduced further information about all surfaces: instead of the code of operation are introduced zero in the case of usual surface and number λ (by octal code) in the case of "formal". For example, if surface of 1 and 3 usual, surface is 2 "is formal", then into nuclei 5222-5224 are introduced the codes

0 00 0000 0000 0000
0 01 0000 0000 0000
0 00 0000 0000 0000

In the third address of nucleus 6137 by octal code is introduced a number of "formal" surfaces.

Printout of the results of calculating the local parameters of gas according to the field of flow is produced periodically after the drawing of a number of trajectories N_{tr}.

Table 8.

Форма входного сечения (1)	Код (2)
Прямоугольник (3)	0 00 0001 0000 0000
Эллипс (4)	0 00 0000 0001 0000

Key: (1). Form of entrance. (2). Code. (3). Rectangle. (4). Ellipse.

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Are printed 5 arrays. In arrays 2-5 to the press/printing are put out 55 groups of numbers (in array 2 - group 1-15, in array 3 - group 16-30, in array 4 - group 31-45, in array 5 - group 46-55) in the sequence, indicated in Table 9. In each group of numbers are contained the values of the corresponding parameter for all "formal" surfaces, in the sequence, which corresponds to numbering $\lambda=1, 2, 3$ .... For example, in the beginning of array 2 are printed all values $W_{+\lambda}$, then all values $W_{-\lambda}$ and so forth. The number, arranged/located in the beginning of each group, i.e., the value of the corresponding parameter for $\lambda=1$, is isolated with the help of index "—" in the 45th digit of the binary code of a number.

Apparently, in certain cases it is useful to use this calculation procedure: through each point of field of flow whose vicinities are investigated, to carry out through three mutually perpendicular "formal" surfaces, and the results of calculation to average according to the formulas:

$$\left.\begin{aligned} n'_k &= \frac{1}{3}\sum_{\lambda=3k-2}^{\lambda=3k} n'_\lambda; \quad T'_k = \frac{1}{3}\sum_{\lambda=3k-2}^{\lambda=3k} T'_\lambda; \\ p'_k &= \frac{1}{3}\sum_{\lambda=3k-2}^{\lambda=3k} p'_\lambda; \quad V'_k = \frac{1}{3}\sum_{\lambda=3k-2}^{\lambda=3k} V'_\lambda. \end{aligned}\right\} \qquad (5.1)$$

In array 1 are printed h'_k, T'_k, p'_k V'_k for all k=1, 2, 3, ... the points of the field (numbers with numbers 1-4 designate n'_1, T'_1, p'_1, V'_1; numbers 5-8 they designate n'_2, T'_2, p'_2, V'_2 and so forth).

Printout of the coefficients of total flows is produced just as in block V, after printout of the coefficients of the local parameters in the field of flow.

Table 9.

№ группы чисел (1)	Параметры массива 2 (2)	№ группы чисел (1)	Параметры массива 3 (2)	№ группы чисел (1)	Параметры массива 4 (2)	№ группы чисел (1)	Параметры массива 5 (2)
1	$W_{+\lambda}$	16	$M'_{-22(\lambda)}$	31	n'_{λ}	46	$p'_{22(\lambda)}$
2	$W_{-\lambda}$	17	$M'_{+33(\lambda)}$	32	$V'_{1(\lambda)}$	47	$p'_{33(\lambda)}$
3	$n'_{+\lambda}$	18	$M'_{-33(\lambda)}$	33	$V'_{2(\lambda)}$	48	$p'_{12(\lambda)}$
4	$n'_{-\lambda}$	19	$M'_{+12(\lambda)}$	34	$V'_{3(\lambda)}$	49	$p'_{23(\lambda)}$
5	$V'_{+1(\lambda)}$	20	$M'_{-12(\lambda)}$	35	T'_{λ}	50	$p'_{13(\lambda)}$
6	$V'_{-1(\lambda)}$	21	$M'_{+23(\lambda)}$	36	$M'_{11(\lambda)}$	51	$q'_{1(\lambda)}$
7	$V'_{+2(\lambda)}$	22	$M'_{-23(\lambda)}$	37	$M'_{22(\lambda)}$	52	$q'_{2(\lambda)}$
8	$V'_{-2(\lambda)}$	23	$M'_{+13(\lambda)}$	38	$M'_{33(\lambda)}$	53	$q'_{3(\lambda)}$
9	$V'_{+3(\lambda)}$	24	$M'_{-13(\lambda)}$	39	$M'_{12(\lambda)}$	54	V'_{λ}
10	$V'_{-3(\lambda)}$	25	$E'_{+1(\lambda)}$	40	$M'_{23(\lambda)}$	55	p'_{λ}
11	$T_{+\lambda}$	26	$E'_{-1(\lambda)}$	41	$M'_{13(\lambda)}$	—	—
12	$T_{-\lambda}$	27	$E'_{+2(\lambda)}$	42	$E'_{1(\lambda)}$	—	—
13	$M'_{+11(\lambda)}$	28	$E'_{-2(\lambda)}$	43	$E'_{2(\lambda)}$	—	—
14	$M'_{-11(\lambda)}$	29	$E'_{+3(\lambda)}$	44	$E'_{3(\lambda)}$	—	—
15	$M'_{+22(\lambda)}$	30	$E'_{-3(\lambda)}$	45	$p'_{11(\lambda)}$	—	—

Key: (1). the group of numbers. (2). Parameters of array.

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6. Block VII(β) and VII(γ) for the detailed calculation of coefficients of the local flows through the surface.

In block I during the calculation of local flows the rectangular region D is divided on 100 equal pads with the help of 18 straight lines, carried out through each side D region in parallel to its sides. In certain cases can be required the division of region on the finer/smaller pads.

In blocks the VII and VIII rectangular region D is divided into 100 equal bands with the help of 99 straight lines, carried out in parallel to the side γ of region D (block VII) or in parallel to the side β of region D(block VIII). Let us designate the areas of bands ΔS_{ω}, moreover the number of area/site $\omega=\beta\in(0-100)$ for block VII and $\omega=\gamma\in(0-100)$ for block VIII. This division D field proves to be useful during the detailed study of local flows, constants along any one side D region.

With the printout of the coefficients of local flows, which occurs periodically after the drawing of a number of trajectories N'_{tp}, are printed 23 arrays of numbers. The arrays 1-11, which contain according to 100 numbers, and Massey 12, who contains 11 numbers, contain information about the average coefficients of the local flows through areas ΔS_{ω} and through entire surface; these arrays are analogous described in block I and given in Table 6.

Let us note that here index $\omega=\beta$ during the use/application of block VII and $\omega=\gamma$ during the use/application of block VIII.

In view of the smallness of areas/sites ΔS_ω are possible the considerable fluctuations of the values of the parameters upon transfer from one area/site to another. Therefore it is convenient to also have the averaged values of the parameters on several areas/sites ΔS_ω. Arrays 13-23, which contain according to 20 numbers, give the averaged values of the parameters, which are contained in arrays 1-11, on five areas/sites ΔS_ω; for example, the parameters, which contain in array 13, are obtained according to the formula

$$p_{+k}=\frac{1}{5}\sum_{\omega=5k-4}^{\omega=5k} p_{+\omega}, \qquad (6.1)$$

where $p_{+\omega}$ — parameters of array 1, and index k takes values of k=1, 2, 3, ..., 20; for array 14 parameters are obtained analogously from array 2, etc.

Printout of the coefficients of the total of flows is produced just as in block I.

7. Block IX for the simplified assignment of the parameters of surfaces.

Applying block IX, it is possible to decrease and to simplify information about the following surfaces, most widespread in practice (Fig. 1-6 and Table 10); parallelogram, trapezoid (triangle), elliptical ring, elliptical cylinder and cone, ellipsoid.

Table 10 gives the order of the location of the parameters of the information, which contains 12 numbers, for each surface. Information about all surfaces whose number is not more than 17, is introduced into nuclei 0420-0733 (into nuclei 0420-0433 about surface of 1, 0434-0447 about surface of 2, etc.).

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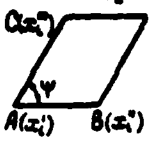
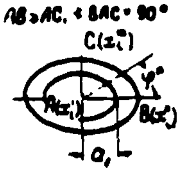
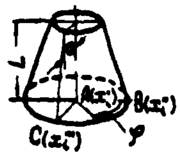
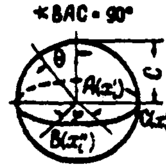
Table 10.

№ sequence	$\psi \le \pi/2$ 		$AB > AC$, $\angle BAC = 90°$ 	$\angle BAC = 90°$ 	$\angle BAC = 90°$ 	$\angle BAC = 90°$ 
1	x_1'					
2	x_2'	x_i'	x_i'	x_i'	x_i'	x_i'
3	x_3'					
4	x_1''					
5	x_2''	x_i''	x_i''	x_i''	x_i''	x_i''
6	x_3''					
7	x_1'''					
8	x_2'''	x_i'''	x_i'''	x_i'''	x_i'''	x_i'''
9	x_3'''					
10	0	b	a_1/AB	$-L$	L	C
11	0	0	$1-\varphi^{\circ}/2\pi$	$1-\varphi/2\pi$	$1-\varphi/2\pi$	$1-\varphi/2\pi$
12	0	$-1,0$	0	0	α	$1-\theta/\pi$

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In Table 10 parameters 1-9 are the coordinates of points A, B and C, arranged/located relative to surface in accordance with Fig. 1-6 and figures, given in Table 10. Coordinates x_i', x_i'' and x_i''' are

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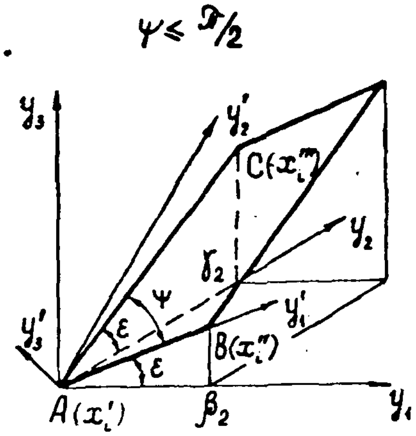

Fig. 1.

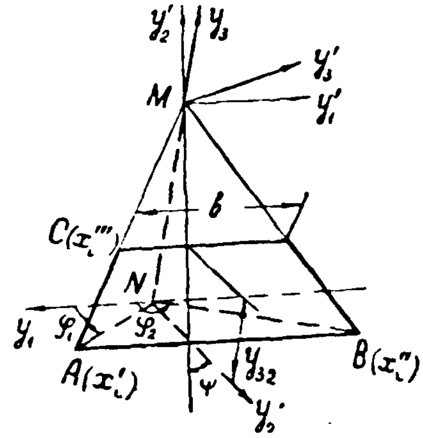

Fig. 2.

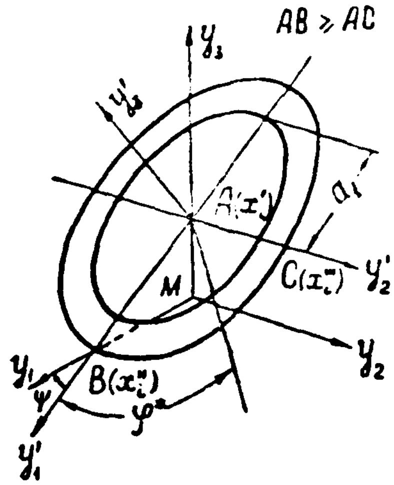

Fig. 3.

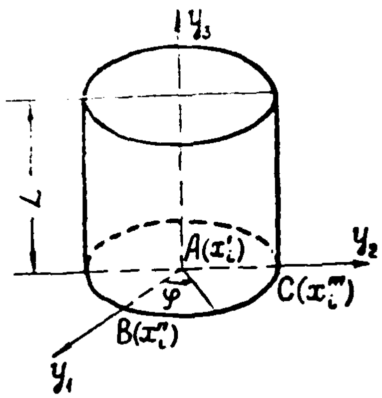

Fig. 4.

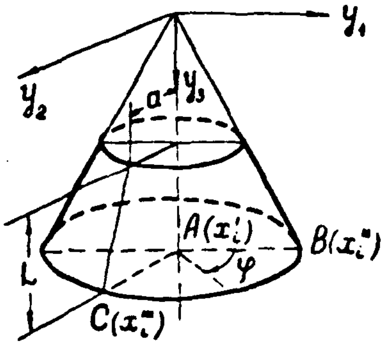

Fig. 5.

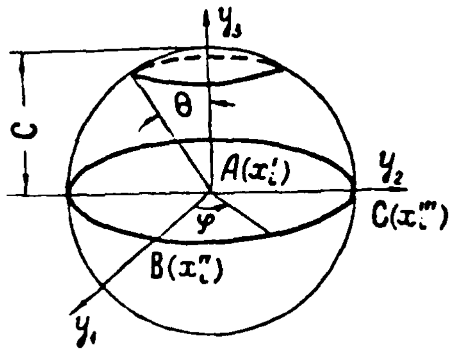

Fig. 6.

assigned in the system of coordinates Xx_i. The angles of longitude/length φ^* and φ and the angle of latitude θ, with the help of which is selected the piece of surface in question, are changed in the ranges: $\varphi^* \in (0-360°)$, $\varphi \in (0-360°)$, $\theta \in (0-180°)$. Angles φ and φ^* are counted off from AB, angle θ is counted off from the line, perpendicular to plane BAC.

If necessary for the recording of the local particle fluxes, impulse/momentum/pulse and energy into nucleus 0330 is sent the number, equal to the reference number of simple surface and which has plus sign during the recording of flows over the external surface and minus sign during the recording of flows over the internal surface. Let us note that the recording of local flows can be produced only over one surface.

Each surface is accompanied by the indicative codes (Table 11), which are joined into the array by way of the location of surfaces in nuclei (0420-0733) and are introduced into nuclei 5201-5221.

In the case when there are only simple surfaces or together with the simple ones there are complicated surfaces information about which can be been given only on Table 2, the information, which composes version, is introduced in the following order: with the address code (AK) 0420 information only about all simple surfaces,

comprised on Table 10; with AK5201 and AK5222 - codes for all surfaces (simple and complicated); AK6616 - number of all surfaces (simple and complicated); with AK 1364 - the number only of simple surfaces; then is placed all remaining information; the necessary blocks, moreover block IX is arranged always for information processing about the simple surfaces: after block IX are introduced zero into nucleus 1345 in the case of the presence together with the simple ones of complicated surfaces, otherwise it is not introduced; then is placed punch card with the check sum, equal to zero; without the address code is placed the information about the complicated surfaces, comprised according to Table 2; version is finished with punch card with the check sum, equal to zero. Information for calculating the local flows according to the complicated surface is introduced according to the description Section of 1 Chapter II. The examples of assignment to information are given in appendix 2.

Let us make some observation about the algorithm of the program of block IX, according to which are calculated the parameters of surfaces, described in block I (see Table 2).

Cosines a_{jl} are determined from the formula

$$a_{jl}=a^{*}_{jm}\,a'_{ml}\,(l,\ m=1,2,3); \qquad (7.1)$$

$$a'_{1l}=\frac{x^{*}_{l}-x'_{l}}{|x^{*}_{l}-x'_{l}|};\quad a'_{2l}=a'_{3l}\times a'_{1l};\quad a'_{3l}=\frac{(x^{*}_{l}-x'_{l})\times(x''_{l}-x'_{l})}{|(x^{*}_{l}-x'_{l})\times(x''_{l}-x'_{l})|}. \qquad (7.2)$$

Here a'_{mi} — cosines of the angles between axes x_i and axes y'_m of the intermediate coordinate system; a'_{jm} — cosines of the angles between axes y_j and y'_m (see Fig. 1-6).

Table 11.

Поверхность (1)	Код (2)				
Параллелограмм (3)	0	00	0000	0000	0000
Трапеция (4)	0	00	0000	0001	0000
Эллиптическое кольцо (5)	0	00	0001	0000	0000
Эллиптические цилиндр и конус (6)	0	00	0000	0001	0000
Эллипсоид (7)	0	00	0000	0000	0001

Key: (1). Surface. (2). Code. (3). Parallelogram. (4). Trapezoid. (5). Elliptical ring. (6). Elliptical cylinder and cone. (7). Ellipsoid.

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The sides of parallelogram AB and AC it is placed in the coordinate planes $y_1 y_3$ and $y_2 y_3$. After conversions we find

$$\left.\begin{aligned} a'_{j1} &= \{\sqrt{1-\cos\psi},\ 0,\ \sqrt{\cos\psi}\}; \\ a'_{j2} &= \left\{\frac{-\cos\psi}{\sqrt{1+\cos\psi}},\ \frac{1}{\sqrt{1+\cos\psi}},\ \left[\frac{\cos\psi(1-\cos\psi)}{1+\cos\psi}\right]^{1/2}\right\}; \\ a'_{j3} &= \left\{-\left[\frac{\cos\psi}{1+\cos\psi}\right]^{1/2},\ -\left[\frac{\cos\psi}{1+\cos\psi}\right]^{1/2},\ \left[\frac{1-\cos\psi}{1+\cos\psi}\right]^{1/2}\right\}. \end{aligned}\right\} \tag{7.3}$$

Equation of the plane of the parallelogram

$$-\left(\frac{\cos\psi}{1-\cos\psi}\right)^{1/2}(y_1+y_2)+y_3-1=0. \tag{7.4}$$

Coordinates of point Y:

$$x_{0i}=x'_i-a_{3i}. \tag{7.5}$$

Limits D region:

$$\beta_1 = 0;\quad \beta_2 = AB\sqrt{1-\cos\psi};\quad \gamma_1 = 0;\quad \gamma_2 = AC\sqrt{1-\cos\psi}. \qquad (7.6)$$

The side of trapezoid AB it is directed in parallel to axis γ_1. ψ - angle between the plane of trapezoid and the plane $\gamma_1\gamma_2$.

From Fig. 2 we note

$$a^{\bullet}_{j1} = \{-1, 0, 0\};\quad a^{\bullet}_{j2} = \{0, -\cos\psi, \sin\psi\};\quad a^{\bullet}_{j3} = \{0, \sin\psi, \cos\psi\}. \qquad (7.7)$$

Equation of the plane of the trapezoid:

$$y_2 \sin\psi + y_3 \cos\psi - MN\cos\psi = 0. \qquad (7.8)$$

Coordinates of point Y, which coincides with point N,

$$\left.\begin{aligned} \vec{x}_{0i} = \vec{x}'_i - \vec{NA},\ \vec{MA} = -\vec{AC}^{\circ}\cdot AB\cdot AC/(AB-b), \\ \vec{MN} = -\vec{a}_{3i}(\vec{a}_{3i}\cdot\vec{AC}^{\circ})\cdot MA,\ \vec{NA} = \vec{MA} - \vec{MN}. \end{aligned}\right\} \qquad (7.9)$$

Limits D region:

$$\left.\begin{aligned} \beta_1 = \varphi_1 = \arcsin(\vec{a}_{2i}\cdot\vec{NA}^{\circ}),\ (\vec{AB}^{\circ}\cdot\vec{NA}^{\circ}) < 0, \\ \beta_2 = \varphi_2 = \arcsin(\vec{a}_{2i}\cdot\vec{NB}^{\circ}),\ (\vec{AB}^{\circ}\cdot\vec{NB}^{\circ}) < 0; \end{aligned}\right\} \qquad (7.10)$$

$$\left.\begin{aligned} \beta_1 = \varphi_1 = \pi - \arcsin(\vec{a}_{2i}\cdot\vec{NA}^{\circ}),\ (\vec{AB}^{\circ}\cdot\vec{NA}^{\circ}) > 0, \\ \beta_2 = \varphi_2 = \pi - \arcsin(\vec{a}_{2i}\cdot\vec{NB}^{\circ}),\ (\vec{AB}^{\circ}\cdot\vec{NB}^{\circ}) > 0; \end{aligned}\right\} \qquad (7.11)$$

$$\gamma_1 = y_{31} = 0,\quad \gamma_2 = y_{32} = (a_{3i}\vec{AC}^{\circ})AC. \qquad (7.12)$$

Here $\vec{AC}°$, $\vec{NA}°$, $\vec{NB}°$, $\vec{AB}°$ - unit vectors.

For the elliptical ring of axis y'_m it is directed so that

$$a^{\circ}_{j1}=\{\cos\psi, 0, -\sin\psi\}, a^{\circ}_{j2}=\{0,1,0\}, a^{\circ}_{j3}=\{\sin\psi, 0, \cos\psi\}, \cos\psi=\frac{AC}{AB}. \quad (7.13)$$

Equation of the plane of the ring:

$$y_1\sin\psi+y_3\cos\psi-(AB\sin\psi+1)\cos\psi=0. \quad (7.14)$$

Coordinates x_{0i} of point Y:

$$x_{0i}=x'_i-a_{3i}(AB\sin\psi+1) \quad (7.15)$$

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The limits D region are calculated from the formulas:

$$\varphi^*=k\cdot\pi/2+\Delta\varphi^*,\ \Delta\varphi^*<\frac{\pi}{2},\ k=0,\ 1,\ 2,\ 3,\ 4;$$

$$\beta_1=\varphi_1=0; \quad (7.16)$$

$$\beta_2=\varphi_2=k\frac{\pi}{2}\ \overset{(1)}{\text{при}}\ |\Delta\varphi^*|<0{,}001; \quad (7.17)$$

$$\left.\begin{aligned}\beta_2&=\varphi_2=\operatorname{arctg}\frac{\operatorname{tg}\varphi^*}{\cos\psi},\ k=0;\\ \beta_2&=\varphi_2=\pi+\operatorname{arctg}\frac{\operatorname{tg}\varphi^*}{\cos\psi},\ k=1,2;\\ \beta_2&=\varphi_2=2\pi+\operatorname{arctg}\frac{\operatorname{tg}\varphi^*}{\cos\psi},\ k=3;\end{aligned}\right\}\ \overset{(1)}{\text{при}}\ |\Delta\varphi^*|>0{,}001 \quad (7.17')$$

$$\gamma_1=AC\frac{a_1}{AB},\quad \gamma_2=AC. \quad (7.18)$$

Key: (1). with.

For the elliptical cylinder

$$\frac{y_1^2}{AB^2}+\frac{y_2^2}{AC^2}=1 \quad \text{(1) (уравнение поверхности)}; \tag{7.19}$$

$$\left.\begin{aligned} a^{*}_{jm} &= \delta_{jm};\\ x_{0\,i} &= x'_i;\\ \beta_1=0,\ \beta_2=\varphi,\ \gamma_1 &= 0,\ \gamma_2=L. \end{aligned}\right\} \tag{7.20}$$

Key: (1). the equation of surface.

For the elliptical cone

$$\frac{y_1^2}{AB^2}+\frac{y_2^2}{AC^2}-\frac{y_3^2}{H^2}=0 \quad \text{(1) (уравнение поверхности)} \tag{7.21}$$

Key: (1). the equation of surface.

where H=AC·L·(AC-a);

$$\left.\begin{aligned} a^{*}_{jm} &= \delta_{jm};\\ x_{0\,i} &= x'_i - a_{3i}H;\\ \beta_1=0,\ \beta_2=\varphi,\ \gamma_1 &= H-L+10^{-5},\ \gamma_2=H. \end{aligned}\right\} \tag{7.22}$$

For the ellipsoid

$$\frac{y_1^2}{AB^2}+\frac{y_2^2}{AC^2}+\frac{y_3^2}{C^2}=1 \quad \text{(1) (уравнение поверхности)}; \tag{7.23}$$

$$\left.\begin{aligned} a^{*}_{jm} &= \delta_{jm};\\ x_{0\,i} &= x'_i;\\ \beta_1=0,\ \beta_2=\varphi,\ \gamma_1 &= 0,\ \gamma_2=\theta. \end{aligned}\right\} \tag{7.24}$$

Key: (1). the equation of surface.

8. Calculations in the flow of Newton and in the flow of light/world.

For the calculations in Newton's flow it is necessary to introduce $S_\infty \gg 1$, $N_\rho = 1$, $p_e = 0$. In nucleus 0251 to send number 0.01. The corresponding coefficients are calculated from formulas (9.1) and (9.2) Chapter I.

For the calculations in the flow of light/world it is necessary to be given $S_\infty \gg 1$, $p_e = k_2$ (portion of the light/world absorbed by surface), $N_\rho > 1$ and to introduce into nucleus 3637 the command/crew

0 00 0051 0000 6520

and into the nucleus 0251 number 0.01.

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The designed coefficients in the flow of light/world are referred to "velocity head" $q_\Phi = \frac{E_\Phi}{2c_0}$.

During calculations in the flow of Newton and in the flow of light/world into nucleus 0332 are sent zero - sign/criterion of the mirror-diffused reflection.

9. On the sequence of the introduction/input of blocks.

During conducting of calculations with the use/application of

several blocks whose possible combinations are given in Table 12, blocks are introduced after block I and version of calculation in the order, which corresponds to an increase in the number of block. In Table 12 blocks I_c and $I_л$ designate block I for calculating the coefficients of total (without the local ones) or local (and total) flows.

10. On the sensors of 0-1 pseudorandom numbers R_1-R_{10} evenly distributed in the interval.

For the work of program it is necessary to develop ten numbers R_1-R_{10}. All ten programs for generating these numbers are obtained of one program (No 1) of obtaining pseudorandom numbers, given in [26]. Were preliminarily calculated the constants of sensor d+1, d+2 and c+1 after obtaining $i \cdot 2 \cdot 10^5$ of pseudorandom numbers. Here i=1, 2, 3, ..., 10. The obtained constants are given in the nuclei of 6713-6750 blocks I. Turning to the program of obtaining random numbers 6676-6704 is produced at the value of index register (RA), equal to the number of address, in which is placed constant d+1. For example, during the turning to the program of sensor 6676-6704 at the value of RA, equal to 6713, constants d+1 and d+2 for the work of sensor are taken from nuclei 6713 and 6714, and next pseudorandom number is obtained in nucleus 6715.

For the work with another sensor it is necessary to introduce the new program of sensor into nuclei 6676-6703 and new constants into nuclei 6713-6750.

In appendix 2 in example 3 are given the program and the constants of another version of the sensor of pseudorandom numbers. Initial sensor with period $2^{33}-1$ was undertaken from work [26] (program No 5). Constants for all ten sensors in example 3 were obtained after drawing $i \cdot 6 \cdot 10^{5}$ ($i=1,2,3, \ldots, 10$) pseudorandom numbers.

Table 12.

	I_c	I_s	II	II + III	IV	V	VI	VII, VIII	IX
I_c	−	+	+	+	+	+	+	+	+
I_s	+	−	+	+	−	+	−	+	+
II	+	+	−	+	+	+	+	+	+
II + III	+	+	+	−	+	+	+	+	+
IV	+	−	+	+	−	+	−	−	+
V	+	+	+	+	+	−	−	+	+
VI	+	−	+	+	−	−	−	−	+
VII, VIII	+	+	+	+	−	+	−	−	+
IX	+	+	+	+	+	+	+	+	−

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11. Examples of calculation.

Let us consider the examples of assignment to initial information for the calculation according to the universal program of aerodynamic coefficients, local flows and parameters of gas for some bodies of the complex form whose diagrams are given in Fig. 7-9. The assignment of numbers and commands/crews for the calculation in these examples, and also the results of calculation are given in appendix 2.

For the compound (see Fig. 7) consisting of simple surfaces of

1-6 (1 - parallelogram, 2 - cone, 3 - cylinder, 4 - trapezoid, 5 - ring, 6 - sphere) and complicated surface of 7 (paraboloid of revolution), it is necessary to calculate aerodynamic coefficients for each surface of 1-7 with the diffuse reflection of molecules with the complete accommodation and with the reflection of molecules in accordance with law (4.11). The order of the location of information in the version and their numerical values are given in example 1 of appendix 2.

In nuclei 0420-0527 is placed the information about the simple surfaces, comprised according to Tables 10; then into the appropriate nuclei are placed the angles of attack α_0, of slip β_0, parameter H in terms of value of which with the help of linear interpolation are calculated values V_∞, $\bar{V}$ and T_∞, accommodation coefficient α_e, portion p_e of the diffuse reflecting molecules, S_M, d_M, coordinate x^0_{1i} and x^0_{2i} the faces of parallelepiped (control surface), coordinate $x'_{\tau i}$ and $x''_{\tau i}$ of two points X and O relative to which must be designed the moment coefficients, the temperature of surface $\bar{T}_w$, of number N_{1p}, N_{2p}, N_{3p}, N_{4p}, the signs/criteria (nuclei 5201-5207) of all surfaces of 1-7 (simple and complicated), number N_{p}, a number of all simple and complicated surfaces (nucleus 6616) and only simple surfaces (nucleus 1364) and a number of remaining parameters (nucleus 6617-6621). Then are placed blocks II, IV and by IX.

In nucleus 1345 are sent zero in the case of the presence together with the simple ones of complicated surfaces, otherwise it is not sent. After punch card with the check sum, equal to zero, is placed the information about complicated surface of 7, comprised according to Table 2.

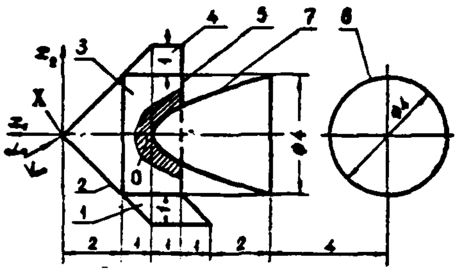

Fig. 7.

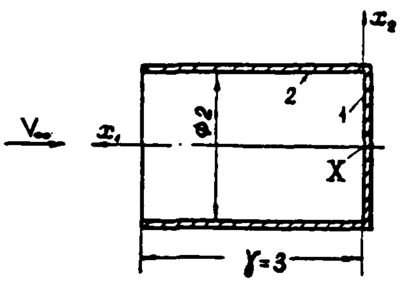

Fig. 8.

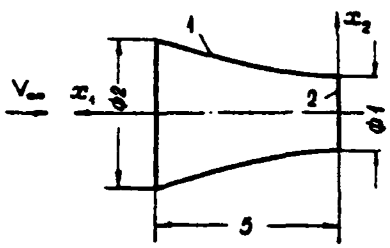

Fig. 9.

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The introduction/input of version (example 1) occurs into two stages: first is introduced the first part of the version (command/crew from nucleus 0006), then the second (loading order from the nucleus of 1350 blocks IX). In appendix 2 is given the array of the aerodynamic coefficients of surface 6, obtained first during the calculation without block II (diffuse reflection of molecules), and then with block II (reflection in accordance with the law (4.11).

In example 2 is examined the problem of calculating the local flows along the height/altitude γ according to inside of the cylinder (see Fig. 8) with those determined of value H, V_∞, $\bar{V}$ and T_∞, sent in the appropriate nuclei (see also the numerical information of block I). Were used the following blocks: V - for the drawing of the start of the molecules through the round entrance and block VIII - for the detailed recording of local flows on the areas/sites, which are obtained during the division of height/altitude γ into one hundred parts. Is given an example of the calculation of the flows of part n_{rk} (k=1, 2, 3, ..., 20) of the multiple reflections on the areas/sites, which are obtained during the division γ into twenty parts, moreover report k is conducted from the basis/base.

In example 3 are given the results of calculating some parameters of gas at the flow through the air intake, which is the element/cell of the hyperboloid (see Fig. 9).

The results of some interesting calculations with the help of the universal program are given also in works [27-29].

Was thoroughly checked the method of drawing of the random parameters of particles. From given for an example Fig. 10 it is evident that the agreement of histograms, obtained with the drawing according to the method of Baird of random values ξ'_{kl} [see density function (3.3)], also, with drawing of speed with the diffuse reflection [see formula (4.10)], with the theoretical data $f(\xi'_{ki})$ and $f_r(\xi'_r) - 2\xi'^3_r \exp(-\xi'^2_r)$ is good even with comparatively small numbers of played trajectories. In Fig. 10 N_e - a number of diffuse reflected particles; by lines they are designated the results of calculations according to precise formulas, by points - according to the Monte Carlo method.

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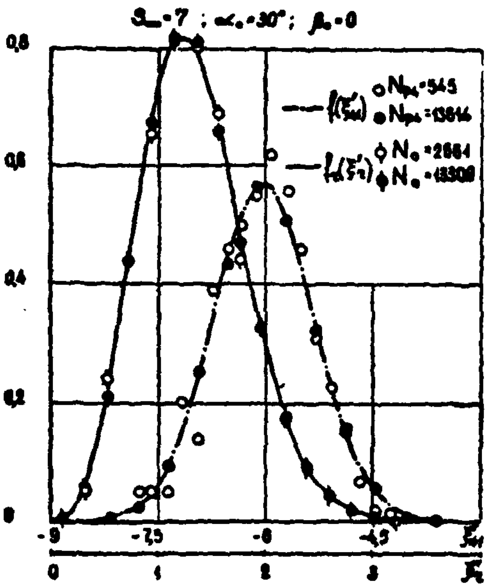

Fig. 10.

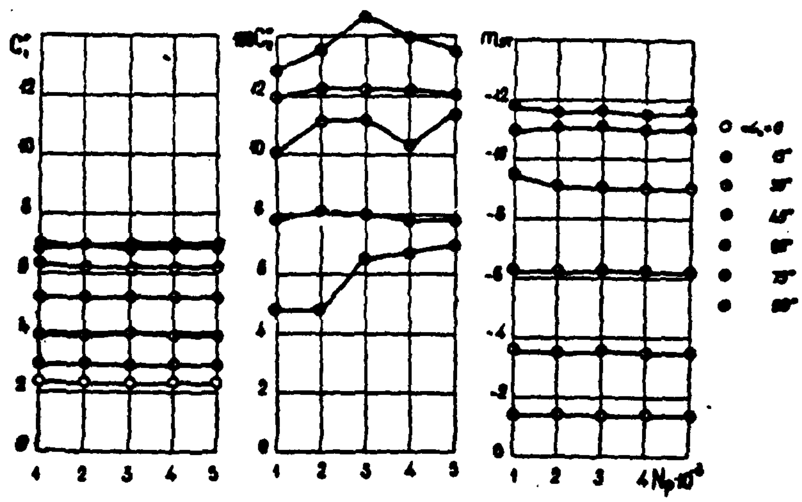

Fig. 11.

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We will designate aerodynamic coefficients in the drag axes by index "0" on top. For the positive reference direction of drag let us take direction V_∞, and for the projection of forces on body axis Xx_1 - opposite direction of axis Xx_1, i.e., in the manner that this is accepted in aerodynamics.

The coordinates of the point, relative to which is designed the moment/torque, we will designate $x_{T i}$, and moment coefficients relatively $x_{T i}$— by subscript "T".

Fig. 11 gives the results of the calculations of total aerodynamic coefficients for ellipsoid $\sum_{j=1}^{3} y_j^2 a_j^{-2} = 1$ at the values of parameters $a_1=10$, $a_2=3$, $a_3=2$, $x_{0i}=0$, $a_{ji}=\delta_{ji}$, $S_\infty=8.265$, $T_\infty=1404°K$, $T_w=320°K$, $\alpha_*=p_*=1$, $x_{T i}=\{10;\ 0;\ 0\}$, $S_M=\pi a_2 a_3$, $d_M=2a_2$. Here δ_{ji} (j, i=1, 2, 3) - unit matrix. Fig. 12 compares the coefficients, obtained by the Monte Carlo method, with the calculated ones, obtained by calculating the integrals over the surface. From the given results it is possible to conclude that an error in the method of Comte-Porta for total coefficients c_1^0 and m_{3T} already when $N_p=10^3$ is within the limits of 3-5%, for obtaining the coefficient c_2^0 with the same

error it is required $N_p \approx$(3-5) by 10^3 and it is more.

Were produced also calculations for the compound, which consists of two ellipsoids, distant behind each other at certain distance. First ellipsoid $\sum_{j=1}^{3} y_j^2 a_j^{-2} = 1$, $a_1=50^{1/2}$, $a_2=90^{1/2}$, $a_3=10$, $x_{0i}=0$, the second ellipsoid $a_1=10$, $a_2=3$, $a_3=2$, $x_{0i}=\{0;\ 12.5;\ -5\ \}$. For both ellipsoids $a_{ji}=\delta_{ji}$. Remaining parameters: $S_\infty=8{,}265$, $T_\infty=1404°$ K, $T_w=320°$ K, $a_{\tau}=p_0=1$, $S_M=2\pi(3+5\sqrt{90})$, $d_M=10$, $x_{\tau i}=\{10;\ 0;\ 0\}$.

In Fig. 13 results of this calculation, in which are considered multiple collisions of particles, they are equal with the results of the approximate computation of coefficients with the help of the integrals in the surfaces. During the calculation of integrals in the surface the local coefficients of tangential and normal impulses/momenta/pulses are considered equal to zero, if vector is opposite V_∞ and carried out from the point in question, it intersects concave surface, otherwise they are computed from the formulas for the single area/site. An error in this calculation will be, obviously, small with $S_\infty \gg 1$, the diffuse reflection of particles and when T_w order T_∞. Fig. 13 shows a good agreement of results of calculation in limits of $\approx$3%.

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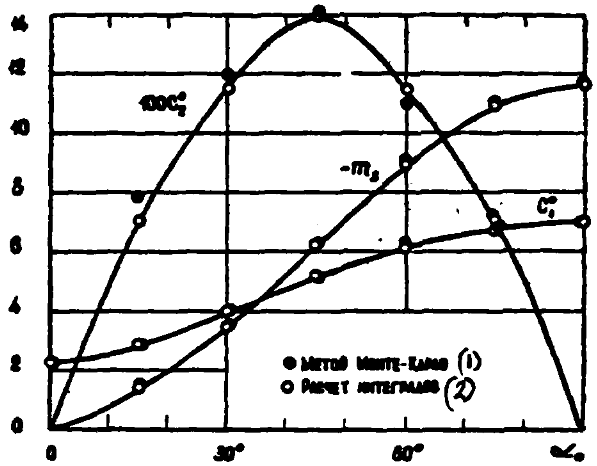

Fig. 12.

Key: (1). Monte Carlo method. (2). Calculation of integrals.

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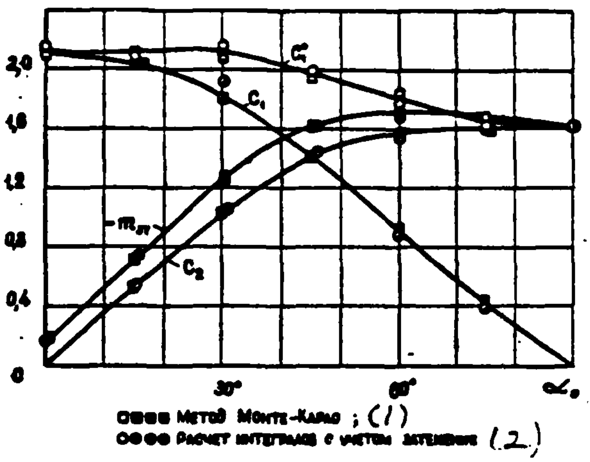

Fig. 13.

Key: (1). Monte Carlo method. (2). Calculation of integrals taking darkening into account.

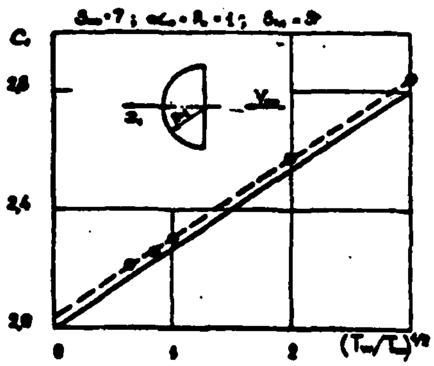

Fig. 14.

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The results of calculations for the concave part of the hemisphere confirm dependences (5.7) (Fig. 14) and with the error less than 1% with $N_p^{\cdot} > 1000$ coincide with the calculation according to the formula

$$c_1 = 2 + 1{,}06\sqrt{\pi}/S_\infty, \tag{11.3}$$

obtained in work [13] for the hypersonic approximation/approach (Fig. 15). Fig. 14 and 15 results of calculations by the method of Monte Carlo depict as small circles, and according to formula (11.3) - by solid lines.

Fig. 16 gives the results of calculating the dispersion of the drag coefficient c_1° and lift c_2° during the flow around single plate of the flow, normal to its surface. Here when $T_w = 0$ (cold surface) is valid the formula

$$\begin{gathered} D[c_1^{\circ}] = 8S_\infty^{-2}\chi^{-1}(S_\infty)\{\exp(-S_\infty^2)[(1+S_\infty^2)/2 - S_\infty M_\mu' + M_\mu'^2/2] + \\ + (1+\operatorname{erf} S_\infty)[\sqrt{\pi}S_\infty(3/2+S_\infty^2)/2 - \sqrt{\pi}M_\mu'(1/2+S_\infty^2) + \sqrt{\pi}S_\infty M_\mu'^2/2]\}, \\ D[c_2^{\circ}] = D[c_3^{\circ}] = 2/S_\infty^2,\ M_\mu' = h_\infty^{1/2}M_\mu = S_\infty + \sqrt{\pi}(1+\operatorname{erf} S_\infty)\chi^{-1}(S_\infty)/2 \end{gathered} \tag{11.4}$$

or when $S_\infty \gg 1$

$$D[c_1^{\circ}] = D[c_2^{\circ}] = D[c_3^{\circ}] \approx 2S_\infty^{-2}. \tag{11.5}$$

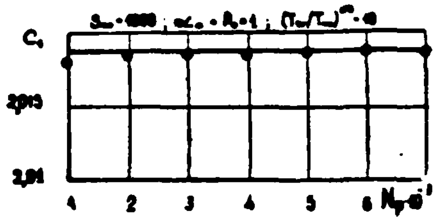

Fig. 15.

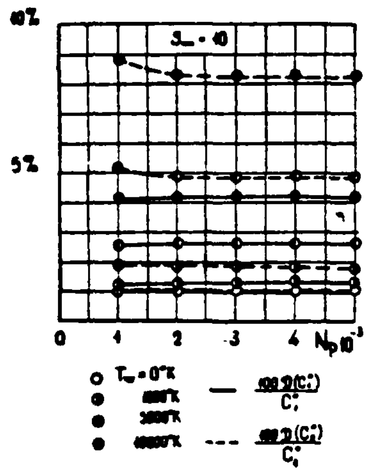

Fig. 16.

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From Fig. 16 it is evident that when $T_w = 0$ the calculations by the Monte Carlo method with an error in less than 1% will be coordinated with the calculations according to formula (11.5).

The author is sincerely grateful to M. N. Kogan for the theme proposed, are more attention to the work and valuable observations. The author is grateful also to V. S. Galkin, V. A. Perepukhov and A. I. Yerofeyev for the useful observations with the execution of work, and also N. I. Larin and Ya. M. Natenzon, attentively read work and made useful observation.

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APPENDIX 1

UNIVERSAL PROGRAM FOR STUDYING INTERNAL AND EXTERNAL FREE-MOLECULAR FLOWS NEAR AN ARBITRARY GROUP OF COMPLEX BODIES

BLOCK I (0)

```
0001 000 0000 0000 0000
0002 000 0000 0000 0000
0003 050 0010 7300 7767 }MO-2
0004 070 7500 0001 0000
0005 030 0001 0006 0077
0006 050 0016 4000 6114
0007 070 4000 0000 0000
0010 050 4412 4000 6114
0011 070 4000 0006 0000
0012 050 0015 2101 2600
0013 070 2101 0000 0000
0014 050 4411 2101 2600
0015 070 2101 0012 0000
0016 000 6135 0000 0016
0017 000 6136 0000 0017
0020 000 0000 0000 0000
0021 000 0000 0000 0000
0022 000 0000 0000 0000
0023 056 0000 0025 0000
0024 000 0000 0000 0000
0025 050 0015 4000 5177
0026 070 4000 0000 0000
0027 050 4411 4000 5177
0030 070 4000 0025 0000
0031 050 0016 0001 0023
0032 070 0001 0000 0000
0033 050 4412 0001 0023
0034 070 0001 0031 0000
0035 050 0016 0025 3776
0036 070 0025 0000 0000
0037 050 4412 0025 3776
```

```
0040 070 0025 0035 0000
0041 050 0016 6116 7767
0042 070 6116 0000 0000
0043 050 4412 6116 7767
0044 070 6116 0041 0000
0045 050 0015 5201 6113
0046 070 5201 0000 0000
0047 050 4411 5201 6113
0050 070 5201 0045 0000
0051 000 0000 0000 0000
0052 000 0000 0000 0000
0053 000 0000 0000 0000
0054 000 0000 0000 0000
0055 072 0000 0000 0000
0056 100 0000 0000 3500
0057 112 0053 0056 0001
0060 050 0411 2101 2600
0061 070 2101 0060 0000
0062 050 0500 0000 0077
0063 070 0077 0000 0000
0064 056 0000 1500 0000
0065 000 0000 0000 0000
0066 050 0412 6116 7767
0067 070 6116 0066 0000
0070 000 0000 0000 0000
0071 000 0000 0000 0000
0072 000 0074 0000 0016
0073 056 0075 0076 0017
0074 000 6135 0000 0016
0075 000 6136 0000 0017
0076 030 0001 0006 0077
```

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1500	052	7032	0000	7615	PM
1501	000	7504	0000	7541	
1502	016	1503	7501	7610	
1503	052	0100	0042	1477	
1504	056	0000	2507	0300	
1505	044	6524	0000	6517	cos θ
1506	005	1417	0051	6661	
1507	005	6520	6517	6657	
1510	003	6661	0000	6661	
1511	003	6657	0000	6657	
1512	052	0000	0002	0000	
1513	056	0300	2655	0000	
1514	002	0340	0337	0021	
1515	002	0342	0341	0022	
1516	002	0344	0343	0023	
1517	005	0022	0023	0024	
1520	005	0021	0023	0025	S_K
1521	005	0021	0022	0026	
1522	072	0000	6611	0000	
1523	400	0260	0000	3500	α_0
1524	072	0000	6612	0000	
1525	400	0274	0000	3501	β_0
1526	072	0000	6613	0000	
1527	400	0310	0000	3502	H
1530	056	0000	3145	1530	
1531	056	0000	4013	0000	
1532	000	0000	0000	0000	
1533	000	0000	0000	0000	
1534	000	0300	0000	0000	
1535	000	0300	0000	0000	
1536	000	0300	0000	0300	
1537	000	0000	0000	0000	
1540	000	0000	0000	0300	
1541	000	0253	0000	3540	
1542	056	0256	3341	3552	E_{KL}^{yre}
1543	005	6640	3540	6662	
1544	005	6641	3540	6663	
1545	005	6642	3540	6664	N_{pk}
1546	005	6643	3540	6665	
1547	005	6644	3540	6666	
1550	005	6645	3540	6667	
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1552	015	6640	0000	0000	
1553	036	0000	1634	0000	
1554	002	6662	6670	0000	
1555	036	0337	1634	0346	I_{11}
1556	001	7761	3521	3521	
1557	001	7761	6670	6670	
1560	072	0000	3715	0000	
1561	016	1562	6676	6704	
1562	400	0002	0000	0341	
1563	005	3731	0041	0041	
1564	001	3726	0041	0041	
1565	016	1566	3562	3572	
1566	005	3554	0042	0042	
1567	001	3720	0042	3720	
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1571	036	0000	1540	0000	
1572	002	3720	7761	3720	
1573	000	0041	0000	0065	

1574	013	3562	7722	3562	
1575	072	0000	3716	0000	
1576	016	1577	6676	6704	
1577	400	0002	0000	0041	
1600	005	3732	0041	0041	
1601	001	3727	0041	0041	
1602	016	1603	3573	3576	
1603	005	0414	0042	0042	
1604	001	3721	0042	3721	
1605	002	3721	7761	0000	
1606	036	0041	1575	0066	
1607	002	3721	7761	3721	
1610	013	3562	7722	3562	
1611	072	0000	3717	0000	
1612	016	1613	6676	6704	
1613	400	0002	0000	0041	
1614	005	3733	0041	0041	
1615	001	3730	0041	0041	
1616	016	1617	3573	3576	
1617	005	0414	0042	0042	
1620	001	3722	0042	3722	
1621	002	3722	7761	0000	
1622	036	0041	1611	0067	
1623	002	3722	7761	3722	
1624	016	1625	1772	2000	
1625	000	3360	0000	3562	
1626	000	0000	0000	0000	
1627	005	6627	0022	0042	
1630	005	6630	0023	0043	
1631	001	0042	0341	0047	I_{12}
1632	001	0043	0343	0050	I_{13}
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1635	000	3772	0000	3724	
1636	013	1573	7721	1573	
1637	033	1606	7721	1606	
1640	013	1566	7724	1566	
1641	052	0000	0000	0000	
1642	500	3734	0000	3726	
1643	112	0005	1642	0001	
1644	013	3570	7724	3570	
1645	000	3713	0000	3715	
1646	000	3712	0000	3716	
1647	013	1557	7723	1557	
1650	000	3720	0000	0041	
1651	000	3721	0000	3720	
1652	000	0041	0000	3721	
1653	015	6641	0000	0000	
1654	036	0000	1665	0000	
1655	002	6663	6671	0000	
1656	036	0341	1665	0047	
1657	015	1660	1556	1626	
1660	005	6627	0021	0043	
1661	005	6630	0023	0044	
1662	001	0043	0337	0045	
1663	001	0044	0343	0050	
1664	016	1655	2005	3111	
1665	000	3711	0000	3723	
1666	000	3773	0000	3725	
1667	013	1573	7721	1573	

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1670	033	1622	7721	1622	
1671	013	1566	7724	1566	
1672	052	0000	0000	0000	
1673	500	3742	0000	3726	
1674	112	0005	1673	0001	
1675	013	3570	7724	3570	
1676	000	3714	0000	3715	
1677	000	3713	0000	3717	
1700	013	1557	7723	1557	
1701	000	3720	0000	0041	
1702	000	3722	0000	3720	
1703	000	0041	0000	3722	
1704	015	6642	0000	0000	
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1707	036	0343	1716	0050	
1710	016	1711	1556	1626	
1711	005	6627	0021	0043	
1712	005	6630	0022	0044	
1713	001	0043	0337	0046	
1714	001	0044	0341	0047	
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1716	013	1606	7721	1606	
1717	013	1622	7721	1622	
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1722	013	1566	7724	1566	
1723	013	1557	7723	1557	
1724	000	3720	0000	0041	
1725	000	3721	0000	3720	
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1727	000	0041	0000	3722	
1730	000	3364	0000	1573	
1731	013	1555	7724	1555	
1732	013	1656	7724	1656	
1733	013	1707	7724	1707	
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1737	500	3772	0000	3723	
1740	502	0000	3772	3707	
1741	112	0002	1735	0001	
1742	500	3745	0000	3723	
1743	112	0024	1742	0001	
1744	000	0000	0000	1626	Draw of
1745	000	0000	0000	0000	
1746	000	0000	0000	0000	N_φ
1747	013	1554	3365	1554	parti-
1750	013	1655	3365	1655	cles
1751	013	1706	3365	1706	
1752	016	1753	1551	1720	
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1755	100	0000	0000	2507	
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1761	000	3366	0000	1566	
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1763	033	1655	3365	1655	

1764	033	1706	3365	1706	
1765	033	1555	7724	1555	
1766	033	1656	7724	1656	
1767	033	1707	7724	1707	
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1771	056	3363	3112	1573	
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1773	016	1774	6676	6704	
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1775	052	0000	6727	0000	
1776	016	1777	6676	6704	
1777	000	6731	0000	6630	
2000	000	0000	0000	0000	
2001	052	0000	6732	0000	
2002	016	2003	6676	6704	
2003	000	6734	0000	6637	
2004	000	0000	0000	0000	
2005	005	0065	3510	0065	
2006	005	0066	3510	0066	ξ^*_{Ki}
2007	005	0067	3510	0067	
2010	005	0065	0065	0075	
2011	005	0066	0066	0076	
2012	005	0067	0067	0077	
2013	001	0075	0076	0075	
2014	001	0075	0077	1476	
2015	044	1476	0000	0051	$\lvert\xi^*_{Ki}\rvert$
2016	004	0065	0051	0036	
2017	004	0066	0051	0037	ξ^0_{Ki}
2020	004	0067	0051	0040	
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2022	056	0000	2030	0000	
2023	452	0000	0000	2026	
2024	100	0000	0000	6624	
2025	112	0016	2024	0001	
2026	000	0000	0000	0000	
2027	056	0000	6577	0000	
2030	000	0000	0000	0000	
2031	452	0000	0000	2034	t_1
2032	500	0420	0000	1440	
2033	112	0035	2032	0001	t_2
2034	000	0000	0000	0000	
2035	015	1470	0000	0000	
2036	036	0000	2043	0053	
2037	000	0000	0000	0054	
2040	016	2041	2112	2120	
2041	016	2042	2144	2153	
2042	056	0000	2210	2120	
2043	005	0036	0036	0052	
2044	005	0037	0037	0053	
2045	005	0040	0040	0054	
2046	005	1441	0052	0052	
2047	005	1442	0053	0053	
2050	005	1443	0054	0054	
2051	005	0036	0037	0056	
2052	005	0037	0040	0057	
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2054	005	1473	0056	0056	
2055	005	1474	0057	0057	
2056	005	1475	0060	0060	
2057	001	0052	0053	0052	

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2060	001	0052	0054	0052	
2061	001	0052	0056	0052	
2062	001	0052	0057	0052	
2063	001	0052	0060	0052	a
2064	000	0000	0000	0000	
2065	005	0046	0036	1417	
2066	005	0046	0037	1420	
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2070	005	0047	0036	1422	
2071	005	0047	0037	1423	
2072	005	0047	0040	1424	
2073	005	0050	0036	1425	
2074	005	0050	0037	1426	
2075	005	0050	0040	1427	
2076	005	1441	1417	1417	
2077	005	1442	1423	1423	
2100	005	1443	1427	1427	
2101	001	1417	1423	0053	
2102	001	1427	0053	0053	
2103	005	7762	0053	0053	
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2105	001	1424	1426	1431	
2106	001	1421	1425	1432	
2107	005	1430	1473	1430	
2110	005	1431	1474	1431	
2111	005	1432	1475	1432	
2112	005	1444	0036	1433	
2113	005	1445	0037	1434	
2114	005	1446	0040	1435	
2115	001	1433	0053	0053	
2116	001	1434	0053	0053	
2117	001	1435	0053	0053	
2120	000	0000	0000	0000	
2121	001	0053	1430	0053	
2122	001	0053	1431	0053	b
2123	001	0053	1432	0053	
2124	005	0046	0046	1417	
2125	005	0047	0047	1420	
2126	005	0050	0050	1421	
2127	005	1441	1417	1417	
2130	005	1442	1420	1420	
2131	005	1443	1421	1421	
2132	005	0046	0047	1422	
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2135	005	1422	1473	1422	
2136	005	1423	1474	1423	
2137	005	1424	1475	1424	
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2142	401	1417	0054	0054	
2143	112	0005	2142	0001	
2144	001	0054	1447	0054	
2145	005	0046	1444	1417	
2146	005	0047	1445	1420	
2147	005	0050	1446	1421	
2150	001	0054	1417	0054	
2151	001	0054	1420	0054	
2152	001	0054	1421	0054	c
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2155	036	0000	2210	0000	
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2157	005	0052	0054	0057	
2160	005	7762	0057	0057	
2161	005	7762	0057	0057	
2162	002	0056	0057	0057	
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2164	044	0057	0000	0057	
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2166	001	0060	0057	0061	
2167	002	0060	0057	0062	
2170	005	7762	0052	0063	
2171	004	0061	0043	0052	t_1
2172	056	0000	3377	0000	
2173	005	0052	0036	1432	
2174	005	0052	0037	1434	
2175	005	0052	0040	1436	
2176	005	0053	0036	1433	
2177	005	0053	0037	1435	
2200	005	0053	0040	1437	
2201	001	0046	1432	0056	
2202	001	0047	1434	0057	I_{im}
2203	001	0050	1436	0060	$m=1$
2204	001	0046	1433	0061	
2205	001	0047	1435	0062	I_{im}
2206	001	0050	1437	0063	$m=2$
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2210	015	0000	0053	0000	
2211	036	0000	2437	2153	
2212	056	0000	3405	0000	
2213	002	0000	0056	0052	
2214	005	0036	0052	1432	
2215	005	0037	0052	1434	
2216	005	0040	0052	1436	
2217	000	1432	0000	1433	
2220	000	1434	0000	1435	
2221	000	1436	0000	1437	
2222	001	0046	1432	0056	
2223	001	0047	1434	0057	
2224	001	0050	1436	0060	
2225	000	0056	0000	0061	
2226	000	0057	0000	0062	
2227	000	0060	0000	0063	
2230	000	0052	0000	0053	
2231	002	0056	1461	0056	
2232	002	0057	1462	0057	
2233	002	0060	1463	0060	
2234	002	0061	1461	0061	
2235	002	0062	1462	0062	
2236	002	0063	1463	0063	
2237	016	2240	7501	7610	
2240	052	1450	0033	0056	
2241	052	0070	0000	0003	
2242	016	2243	7501	7610	
2243	052	1450	0033	0061	
2244	052	0073	0000	0003	
2245	000	0070	0000	1423	
2246	000	0073	0000	1424	
2247	000	0071	0000	1425	

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2250	000	0074	0000	1426
2251	000	0072	0000	1427
2252	000	0075	0000	1430
2253	015	1472	0000	0000
2254	076	0000	2313	3477
2255	056	0000	2261	0000
2256	000	0345	0000	0070
2257	000	3446	0000	2304
2260	000	0000	0000	0000
2261	072	0000	3477	0000
2262	402	1427	0000	0000
2263	236	0000	2306	0000
2264	500	1423	0000	0074
2265	500	1425	0000	0076
2266	202	1465	0074	0000
2267	236	0000	2306	0000
2270	402	0074	1464	0000
2271	236	0000	2306	0000
2272	202	1467	0076	0000
2273	236	0000	2306	0000
2274	402	0076	1466	0000
2275	236	0000	2306	0000
2276	556	0052	2303	0070
2277	000	0000	0000	0000
2300	000	0000	0000	0000
2301	000	0000	0000	0000
2302	000	0000	0000	0000
2303	000	0000	0000	0000
2304	000	3446	0000	2304
2305	056	3476	2261	3477
2306	056	3476	2256	3477
2307	056	0345	2432	0071
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2312	000	0000	0000	0000
2313	015	7724	1472	0000
2314	076	0000	2351	0000
2315	000	3450	0000	2305
2316	056	3451	2321	2306
2317	000	0345	0000	0070
2320	000	3446	0000	2304
2321	072	0000	3477	0000
2322	402	1427	0000	0000
2323	236	0000	2306	0000
2324	605	1423	1423	0060
2325	605	1425	1425	0061
2326	001	0060	0061	0060
2327	144	0060	0000	0076
2330	215	0000	0076	0000
2331	076	0000	2334	0000
2332	100	0000	0000	0074
2333	056	0000	2344	0000
2334	604	1423	0076	0062
2335	016	2336	7501	7610
2336	075	0062	0006	0061
2337	402	1425	0000	0000
2340	056	0000	2343	0000
2341	102	7756	0061	0074
2342	056	0000	2344	0000
2343	101	0412	0061	0074

Check that molecules land in region D (2253-2442)

2344	000	0000	0000	0000
2345	000	0000	0000	0000
2346	056	0000	2266	0000
2347	000	0000	0000	0000
2350	000	0000	0000	0000
2351	015	7722	1472	0000
2352	076	0000	2365	0000
2353	000	3453	0000	2305
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2355	000	0345	0000	0070
2356	072	0000	3477	0000
2357	000	3452	0000	2344
2360	056	0000	2324	0000
2361	000	0000	0000	0000
2362	000	3446	0000	2304
2363	072	0000	3477	0000
2364	056	0000	2324	0000
2365	015	7721	1472	0000
2366	076	0000	2426	0000
2367	000	3456	0000	2305
2370	000	3457	0000	2306
2371	000	3455	0000	2344
2372	000	0000	0000	0000
2373	056	0000	2415	0000
2374	000	0000	0000	0000
2375	000	0000	0000	0000
2376	000	0000	0000	0000
2377	000	0000	0000	0000
2400	605	1427	1427	0062
2401	001	0060	0062	0060
2402	044	0060	0000	0060
2403	015	0000	0060	0000
2404	076	0000	2407	0000
2405	100	0000	0000	0076
2406	056	0000	2344	0000
2407	404	1427	0060	0060
2410	016	2411	7501	7610
2411	075	0060	0006	0061
2412	102	7756	0061	0076
2413	056	0000	2346	0000
2414	000	0000	0000	0000
2415	072	0000	3477	0000
2416	000	0345	0000	0070
2417	056	0000	2324	0000
2420	000	0000	0000	0000
2421	000	3446	0000	2304
2422	072	0000	3477	0000
2423	056	0000	2324	0000
2424	000	0000	0000	0000
2425	000	0040	0000	0000
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2427	070	7747	0000	0000
2430	077	0000	0000	0000
2431	000	0000	0000	0000
2432	000	3467	0000	2304
2433	000	3460	0000	2305
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2436	056	0000	3411	3477
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2440	000	0345	0000	0071	
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2443	002	0070	0071	0000	
2444	076	0000	2447	0000	t_{min}
2445	000	0070	0000	0370	
2446	056	0000	2450	0000	(2443-2505)
2447	000	0071	0000	0370	
2450	000	2032	0000	0347	
2451	000	0000	0000	0000	
2452	013	7722	6610	6610	
2453	015	6610	6616	0000	
2454	036	0000	2463	0000	
2455	013	7721	2445	2445	
2456	013	7721	2447	2447	
2457	013	7721	2450	2450	
2460	013	2032	3443	2032	
2461	000	0000	0000	0000	
2462	056	0000	2031	0000	
2463	000	0000	0000	0000	
2464	000	3462	0000	2032	
2465	000	3463	0000	2445	
2466	000	3464	0000	2447	
2467	000	3465	0000	2450	
2470	000	0000	0000	6610	
2471	015	6616	7722	0000	
2472	036	0000	2515	0000	
2473	452	0000	0000	2504	
2474	202	0370	0371	0000	
2475	076	0000	2501	0000	
2476	000	0370	0000	0370	
2477	000	0347	0000	0347	
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2502	400	0350	0000	0347	
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2505	000	0000	0000	0000	
2506	056	0000	2515	0000	
2507	016	2510	7501	7610	
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2511	016	2512	7501	7610	
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2516	036	0000	2522	0000	
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2520	036	0000	3110	0000	
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2523	452	0000	0000	2526	
2524	000	0000	0000	0000	
2525	112	0035	2524	0001	
2526	000	0000	0000	0000	
2527	000	0000	0000	2524	
2530	000	0370	0000	0070	t_{min}
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2532	005	0037	0070	0072	
2533	005	0040	0070	0073	

2534	001	0046	0071	6525	
2535	001	0047	0072	6526	$I_{\tau l}$
2536	001	0050	0073	6527	
2537	005	1441	6525	1417	
2540	005	1417	7762	1417	
2541	005	6526	1473	1422	
2542	005	6527	1475	1425	
2543	005	1442	6526	1420	
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2560	072	0000	0000	0000	
2561	701	1444	0052	0052	
2562	112	0002	2561	0001	
2563	705	0047	0047	1414	
2564	112	0005	2563	0001	
2565	001	1417	1420	1417	
2566	001	1417	1421	1417	
2567	044	1417	0000	1417	
2570	002	0000	1417	1417	
2571	504	0044	1417	0044	n_i
2572	112	0010	2571	0001	
2573	005	0036	0052	1420	
2574	005	0037	0053	1421	
2575	005	0040	0054	1422	
2576	001	1420	1421	1420	
2577	001	1420	1422	1417	$\xi^{\circ}_{+\tau l}\, n_i$
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2601	002	6637	0334	0000	
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2603	072	0000	0000	0000	
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2606	001	1423	1424	1423	
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2627	005	0052	0056	1424	

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2706	005	0065	6526	1425	
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3076 005 6522 6526 1425
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3205 072 0000 0000 0000
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3207 112 0005 3206 0001
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Calculation of dispersions (3170-3255)

DOC = 83067305 PAGE 242

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3213	001	3277	7761	3300
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3224	112	0005	3223	0001
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3377	004	0062	0063	00[illegible]

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3566	075	0042	0003	0043
3567	000	0000	0000	0000

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3756	000	0000	0000	0000
3757	000	0000	0000	0000

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3760	000	0000	0000	0000	
3761	000	0000	0000	0000	
3762	000	0000	0000	0000	
3763	000	0000	0000	0000	
3764	000	0000	0000	0000	
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3766	000	0000	0000	0000	
3767	000	0000	0000	0000	
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4003	000	0000	0000	0000	
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4006	000	0000	0000	0000	
4007	000	0000	0000	0000	
4010	072	0000	6614	0000	
4011	400	0313	0000	3503	α_*
4012	000	0000	0000	0000	
4013	000	0000	0000	0000	
4014	000	0000	0000	0000	
4015	000	0000	0000	0000	
4016	004	3500	7754	0032	
4017	004	3501	7754	0034	
4020	002	7756	0032	0033	
4021	002	7756	0034	0035	
4022	452	0000	0000	4026	
4023	016	4024	7501	7610	
4024	575	0032	0005	0036	
4025	112	0003	4023	0001	
4026	000	0000	0000	0000	
4027	000	0037	0000	0016	
4030	000	0041	0000	0017	
4031	000	0036	0000	0020	
4032	000	5010	0000	3114	
4033	005	0037	0041	0013	$\cos\alpha_0 \cos\beta_0$
4034	005	0036	0041	0014	
4035	002	0000	0014	0016	$-\sin\alpha_0 \cos\beta_0$
4036	000	0040	0000	0015	$\sin\beta_0$
4037	000	0036	0000	0020	$\sin\alpha_0$
4040	452	0000	0000	4046	
4041	016	4042	7501	7510	
4042	000	0006	0150	0100	
4043	075	3502	0107	3504	$V_\infty, \bar{V}, T_\infty$
4044	013	4043	3472	4043	
4045	112	0002	4041	0001	
4046	000	0000	0000	0000	
4047	056	3473	4470	4043	
4050	005	3505	0415	3510	$\rho_\infty^{-1/2}$
4051	004	3504	3510	3515	S_∞
4052	056	0000	4066	0000	
4053	100	0000	0030	0350	

4054	001	0041	0246	0043	
4055	044	0043	0000	0043	
4056	105	0247	0043	0056	
4057	056	0000	4176	0000	
4060	000	0000	0000	0003	
4061	000	0003	0000	0000	
4062	052	1421	0033	5573	
4063	052	5632	0000	0003	
4064	000	0000	0000	0000	
4065	000	0000	0000	0000	
4066	000	0000	0000	3517	
4067	452	0000	0000	4120	
4070	205	3515	0013	0041	
4071	002	0000	0041	0041	
4072	100	0041	0000	3772	$V'_{\infty K}$
4073	005	0041	0041	0042	
4074	002	0000	0042	0042	
4075	016	4076	7501	7610	
4076	075	0041	0031	0043	
4077	016	4100	7501	7610	
4100	075	0042	0003	0044	
4101	001	7761	0043	0043	
4102	005	0043	0041	0043	
4103	005	0043	0416	0043	
4104	001	0043	0044	0046	
4105	205	0046	0026	0046	
4106	100	0046	0000	0027	
4107	001	0046	3517	3517	
4110	112	0002	4070	0001	
4111	000	0000	0000	0000	
4112	072	0000	0000	0000	
4113	000	4071	0000	0050	
4114	013	4072	3474	4072	
4115	013	4106	3474	4106	
4116	000	0000	0000	4071	
4117	016	4120	4070	4111	
4120	000	0000	0000	0000	
4121	000	0050	0000	4071	
4122	000	0000	0000	4111	
4123	033	4072	3474	4072	
4124	033	4106	3474	4106	
4125	072	0000	0000	0000	
4126	504	0027	3517	6640	N_{pK}/N_p
4127	112	0005	4126	0001	
4130	004	7761	3515	0041	
4131	005	7762	0414	0042	
4132	005	0041	3517	3517	B
4133	004	3517	0042	3517	
4134	005	3510	3510	0043	
4135	004	0250	3506	0044	
4136	005	0043	0044	3547	ρ_w^{-1}
4137	044	3547	0000	3551	
4140	004	0027	0024	0027	
4141	004	0030	0025	0030	
4142	004	0031	0026	0031	$\chi(V'_{\infty}$
4143	004	0032	0024	0032	
4144	004	0033	0025	0033	
4145	004	0034	0026	0034	
4146	452	0000	0000	4153	
4147	402	0027	0326	0000	

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4150	076	0000	4152	0000	
4151	100	0000	0000	6640	
4152	112	0005	4147	0001	
4153	000	0000	0000	0000	
4154	452	0000	0000	4177	
4155	400	3772	0000	0041	ξ^{ra}_{KL}
4156	002	0041	0000	0000	
4157	036	0000	4167	0000	$\xi^{r\theta}_{KL}$
4160	101	0041	0251	0056	
4161	000	0000	0000	0000	
4162	002	0041	0251	0042	
4163	076	0000	4165	0000	
4164	156	0000	4176	0050	
4165	102	0041	0251	0050	
4166	056	0000	4176	0000	
4167	003	0041	0246	0043	
4170	036	0000	4053	0000	
4171	100	0000	0000	0050	
4172	100	0000	0000	0056	
4173	156	0000	4176	6640	
4174	000	0000	0000	0000	
4175	000	0000	0000	0000	
4176	112	0005	4155	0001	
4177	000	0000	0000	0000	
4200	452	0000	0000	4226	
4201	415	6640	0000	0000	$f^{-1}(\xi'_{foo})$
4202	036	0000	4225	0000	f_{max}
4203	000	0000	0000	0000	
4204	404	3772	7762	0041	
4205	005	0041	0041	0042	
4206	001	7764	0042	0042	
4207	044	0042	0000	0042	
4210	001	0041	0042	0042	
4211	202	0042	3772	0041	
4212	005	0041	0041	0041	
4213	002	0000	0041	0041	
4214	016	4215	7501	7610	
4215	075	0041	0003	0043	
4216	005	7762	0043	0043	
4217	204	0043	0027	0041	
4220	005	0042	0041	0041	
4221	000	0000	0000	0000	
4222	104	7761	0041	3554	
4223	000	0000	0000	0000	
4224	000	0000	0000	0000	
4225	112	0005	4201	0001	
4226	000	0000	0000	0000	
4227	000	0000	0000	0000	
4230	052	0000	0000	0000	
4231	415	6640	0000	0000	
4232	036	0000	4234	0000	
4233	304	7762	0027	2507	$2/\chi(V'_{max})$
4234	112	0005	4231	0001	
4235	052	0000	0000	0000	
4236	000	0050	0000	3726	
4237	002	3773	0251	3727	
4240	002	3774	0251	3730	
4241	002	0056	0050	3731	
4242	001	0251	0251	3732	
4243	001	0251	0251	3733	

4244	000	0051	0000	3734
4245	002	3772	0251	3735
4246	002	3774	0251	3736
4247	002	0057	0051	3737
4250	001	0251	0251	3740
4251	001	0251	0251	3741
4252	000	0052	0000	3742
4253	002	3772	0251	3743
4254	002	3773	0251	3744
4255	002	0060	0052	3745
4256	001	0251	0251	3746
4257	001	0251	0251	3747
4260	000	0053	0000	3750
4261	002	3773	0251	3751
4262	002	3774	0251	3752
4263	002	0061	0053	3753
4264	001	0251	0251	3754
4265	001	0251	0251	3755
4266	056	0000	4610	0000
4267	000	0000	0000	0000
4270	000	0000	0000	0000
4271	000	0000	0000	0000
4272	000	0013	0000	1421
4273	000	0014	0000	1422
4274	000	0015	0000	1423
4275	000	0020	0000	1424
4276	000	0016	0000	1425
4277	000	0000	0000	1426
4300	005	0016	0015	1427
4301	002	0000	1427	1427
4302	005	0015	0020	1430
4303	000	0017	0000	1431
4304	000	1433	0000	0074
4305	000	1434	0000	0075
4306	056	0000	4667	0000
4307	000	0000	0000	0000
4310	000	0000	0000	0000
4311	000	0000	0000	0000
4312	000	0000	0000	0000
4313	000	0000	0000	0000
4314	005	3524	3505	0055
4315	005	3523	3506	0056
4316	005	3522	3506	0057
4317	005	3524	3504	0060
4320	005	3523	3504	0061
4321	005	3522	3505	0062
4322	002	0056	0055	0055
4323	002	0060	0057	0056
4324	002	0062	0061	0057
4325	504	0047	0336	0047
4326	112	0010	4325	0001
4327	701	0044	3514	0044
4330	112	0013	4327	0001
4331	016	4332	7501	7610
4332	052	1421	0033	3522
4333	052	3530	0000	0003
4334	016	4335	7501	7610
4335	052	1421	0033	0055
4336	052	3533	0000	0003
4337	000	0000	0000	1421

4340	072	0000	0000	0000
4341	605	3522	3522	1422
4342	001	1421	1422	1421
4343	112	0002	4341	0001
4344	044	1421	0000	1420
4345	504	3517	1420	1417
4346	112	0005	4345	0001
4347	005	3526	3524	1425
4350	005	3527	3523	1426
4351	005	3527	3522	1427
4352	005	3525	3524	1430
4353	005	3525	3523	1431
4354	005	3526	3522	1432
4355	002	1425	1426	1425
4356	002	1427	1430	1426
4357	002	1431	1432	1427
4360	000	0000	0000	1421
4361	000	0000	0000	0000
4362	000	0000	0000	0000
4363	072	0000	0000	0000
4364	605	1425	1425	1430
4365	001	1430	1421	1421
4366	112	0002	4364	0001
4367	044	1421	0000	1421
4370	015	1421	0000	0000
4371	076	0000	4404	0000
4372	000	0000	0000	3542
4373	000	0000	0000	3543
4374	000	0000	0000	3544
4375	000	3525	0000	3545
4376	000	3526	0000	3546
4377	000	3527	0000	3547
4400	000	0000	0000	0000
4401	000	0000	0000	0000
4402	000	0000	0000	0000
4403	056	0000	4433	0000
4404	504	1422	1421	1422
4405	112	0005	4404	0001
4406	005	1423	1427	1430
4407	005	1424	1426	1433
4410	005	1424	1425	1431
4411	005	1422	1427	1434
4412	005	1422	1426	1432
4413	005	1423	1425	1435
4414	702	1422	1425	1422
4415	112	0010	4414	0001
4416	016	4417	7501	7610
4417	052	1422	0033	3525
4420	052	1433	0000	0003
4421	000	0000	0000	0000
4422	000	0000	0000	0000
4423	005	1435	0336	1436
4424	004	1436	1420	1436
4425	305	1436	1414	3531 x_{10}
4426	112	0013	4425	0001
4427	302	0000	3526	3526
4430	112	0016	4427	0001
4431	305	1433	1403	3526
4432	112	0021	4431	0001
4433	000	0000	0000	0000

4434	005	0331	5501	5501
4435	005	0331	5511	5511
4436	005	0331	5521	5521
4437	005	0331	5532	5532
4440	005	0331	5535	5535
4441	005	0331	5540	5540
4442	005	0331	5543	5543
4443	005	0331	5547	5547
4444	005	0331	5552	5552
4445	005	0331	5555	5555
4446	005	0331	5560	5560
4447	005	0331	5564	5564
4450	056	0000	5037	0000
4451	056	0000	4520	0000
4452	050	0411	4000	5177
4453	070	4000	4452	0000
4454	000	0000	0000	6610
4455	013	7722	6611	6611
4456	015	6611	6617	0000
4457	076	0000	1514	3521
4460	000	0000	0000	6611
4461	013	7722	6612	6612
4462	015	6612	6620	0000
4463	076	0000	1514	0000
4464	000	0000	0000	6612
4465	013	7722	6613	6613
4466	015	6613	6621	0000
4467	076	0000	1514	0000
4470	000	0000	0000	6613
4471	013	7722	6614	6614
4472	015	6614	6622	0000
4473	076	0000	1514	0000
4474	000	0000	0000	6614
4475	056	0000	3340	0000
4476	003	3504	7757	0000
4477	076	5011	4050	6553
4500	000	4503	0000	4130
4501	000	4504	0000	3114
4502	056	4505	4050	6553
4503	000	7761	0000	0041
4504	004	3510	7762	1437
4505	005	3510	3510	1432
4506	000	0000	0000	0000
4507	000	0000	0000	0000
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4512	000	0000	0000	0000
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4520	004	0074	3514	0070
4521	004	0075	3514	0071
4522	005	0070	0070	0072
4523	005	0071	0071	0073
4524	052	0000	0000	0000
4525	504	3307	0070	5671
4526	504	3312	0071	5674
4527	504	3323	0072	5700

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4530	504	3326	0073	5703
4531	544	5700	0000	5707
4532	544	5703	0000	5712
4533	505	5707	7763	5716
4534	505	5712	7763	5721
4535	000	0000	0000	0000
4536	112	0002	4525	0001
4537	052	0000	0000	0000
4540	500	6000	0000	3500
4541	112	0053	4540	0001
4542	000	0000	0000	0000
4543	000	0000	0000	0000
4544	002	3540	3552	0000
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4550	001	3552	0256	3552
4551	000	0000	0000	0000
4552	000	0000	0000	0000
4553	000	0000	0000	0000
4554	056	0000	4654	0000
4555	100	0000	0000	3500
4556	112	0053	4555	0001
4557	072	0000	0000	0000
4560	100	0000	0000	3271
4561	112	0037	4560	0001
4562	000	0000	0000	0000
4563	000	0000	0000	0000
4564	072	0000	0000	0000
4565	100	0000	0000	6570
4566	112	0005	4565	0001
4567	056	0000	4452	0000
4570	000	0000	0000	0000
4571	050	0412	0001	0023
4572	070	0001	4571	0000
4573	050	0412	0025	3776
4574	070	0025	4573	0000
4575	050	0411	5201	6113
4576	070	5201	4575	0000
4577	056	0000	0066	0000
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4601	000	0000	0000	0000
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4605	000	0000	0000	0000
4606	000	0000	0000	0000
4607	000	0000	0000	0000
4610	000	0054	0000	3756
4611	002	3772	0251	3757
4612	002	3774	0251	3760
4613	002	0062	0054	3761
4614	001	0251	0251	3762
4615	001	0251	0251	3763
4616	000	0055	0000	3764
4617	002	3772	0251	3765
4620	002	3773	0251	3766
4621	002	0063	0055	3767
4622	001	0251	0251	3770
4623	001	0251	0251	3771

4624	056	0000	4630	0000
4625	000	0000	6713	0000
4626	000	0000	6716	0000
4627	000	0000	6721	0000
4630	500	3772	0000	3707
4631	500	4625	0000	3712
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4636	000	0000	0000	0000
4637	072	0000	3715	0000
4640	016	4641	6676	6704
4641	000	6715	0000	3720
4642	072	0000	3716	0000
4643	016	4644	6676	6704
4644	000	6720	0000	3721
4645	072	0000	3717	0000
4646	016	4647	6676	6704
4647	000	6723	0000	3722
4650	000	0000	0000	0000
4651	056	0000	5061	0000
4652	000	0000	0000	0000
4653	056	3362	6507	6513
4654	002	3540	0254	0000
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4656	000	0000	0000	0000
4657	000	0000	0000	0000
4660	000	0000	0000	0000
4661	000	0000	0000	0000
4662	072	0000	0000	0000
4663	056	0000	4555	0000
4664	001	0253	3540	3540
4665	055	0000	6543	0000
4666	000	0000	0000	0000
4667	052	0000	0000	0000
4670	500	3500	0000	6000
4671	112	0053	4670	0001
4672	000	3500	0000	5501
4673	000	3501	0000	5502
4674	000	3502	0000	5503
4675	000	3515	0000	5504
4676	004	3504	3551	5505
4677	000	3504	0000	5506
4700	000	3506	0000	5507
4701	000	0250	0000	5510
4702	000	3503	0000	5511
4703	000	0334	0000	5512
4704	000	3517	0000	5513
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4706	000	3520	0000	5515
4707	000	3514	0000	5516
4710	000	3516	0000	5517
4711	004	3520	3514	5520
4712	005	3507	1435	5521
4713	005	3511	1435	5522
4714	005	3512	1435	5523
4715	001	5521	5522	5524
4716	001	5524	5523	5525
4717	001	5522	5523	5526

Draw of N_{pz} molecules

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4720	005	3537	1435	5527
4721	000	0000	0000	5530
4722	000	7730	0000	5531
4723	000	7730	0000	5546
4724	000	7730	0000	5563
4725	000	7730	0000	5572
4726	000	7730	0040	5631
4727	000	7730	0000	5670
4730	000	7730	0000	5677
4731	000	7730	0000	5706
4732	000	7730	0000	5715
4733	000	7730	0000	0000
4734	072	0000	0000	0300
4735	504	3522	1433	5573
4736	504	3530	1433	5615
4737	504	3541	1433	5623
4740	504	3525	1434	5576
4741	504	3533	1434	5620
4742	504	3544	1434	5626
4743	112	0002	4735	0001
4744	052	0000	0000	0000
4745	701	5615	5623	5601
4746	701	5615	5573	5607
4747	112	0005	4745	0001
4750	052	0000	0000	0000
4751	016	4752	7501	7610
4752	052	1421	0033	5573
4753	052	5632	0000	0003
4754	013	4752	4060	4752
4755	013	4753	4061	4753
4756	112	0011	4751	0001
4757	000	4062	0000	4752
4760	000	4063	0000	4753
4761	052	0000	0000	0000
4762	701	5573	5601	5532
4763	701	5632	5640	5547
4764	500	5532	0000	3522
4765	500	5547	0000	3530
4766	112	0005	4762	0001
4767	000	0000	0000	0000
4770	000	0000	0000	0000
4771	000	0000	0000	0000
4772	000	0000	0000	0000
4773	000	0316	0000	3504
4774	000	0320	0000	3505
4775	000	0322	0000	3506
4776	052	0000	0006	0000
4777	016	5000	4314	4433
5000	000	0000	0000	4433
5001	052	0000	0000	0000
5002	500	3542	0000	5564
5003	500	3545	0000	5567
5004	500	0055	0000	5540
5005	500	3533	0000	5555
5006	112	0002	5002	0001
5007	056	0000	5020	0000
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5013	000	0000	0000	0000

5014	000	0000	0000	0000	
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5016	000	0000	0000	0000	
5017	000	0000	0000	0000	
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5021	016	5022	4272	4304	
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5023	000	4340	0000	5010	
5024	000	0317	0000	3504	
5025	000	0321	0000	3505	
5026	000	0323	0000	3506	
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5032	052	0000	0000	0000	
5033	500	0055	0000	5543	
5034	500	3533	0000	5560	
5035	112	0002	5033	0001	
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5037	005	0331	5567	5567	
5040	005	0331	5573	5573	
5041	005	0331	5601	5601	
5042	005	0331	5607	5607	
5043	005	0331	5615	5615	
5044	005	0331	5623	5623	
5045	005	0331	5632	5632	
5046	005	0331	5640	5640	
5047	005	0331	5646	5646	
5050	005	0331	5654	5654	
5051	005	0331	5662	5662	
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Calculation ΔS_w

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6233	016	2772	2603	2622
6234	002	6637	0334	0000
6235	076	0000	6233	0000
6236	056	0000	2772	0000
6237	005	1417	0051	6661

6240	003	6661	0000	6661
6241	056	6662	2674	6657
6242	000	0000	0000	0000
6243	000	0000	0000	0000
6244	000	0000	0000	0000
6245	000	1420	0000	6242
6246	000	1421	0000	6243
6247	056	1422	3040	6244
6250	000	6242	0000	1420
6251	000	6243	0000	1421
6252	056	6244	3105	1422
6253	000	0000	0000	0000
6254	054	0050	1440	0001
6255	033	0001	7722	0001
6256	072	0000	0001	0000
6257	016	3170	3645	3653
6260	000	0000	0000	0000
6261	015	3550	0000	0000
6262	076	0000	6266	0000
6263	001	7761	3514	3514
6264	001	1476	3507	3507
6265	056	0000	2545	0000
6266	001	7761	3516	3516
6267	001	1476	3512	3512
6270	056	0000	2545	0000
6271	015	3550	0000	0000
6272	076	0000	6277	0000
6273	002	3511	6521	3511
6274	052	0000	0006	0000
6275	016	6245	3066	6302
6276	000	0000	0000	0000
6277	002	3512	6521	3512
6300	056	0000	3040	0000
6301	502	3527	1422	3527
6302	000	0000	0000	0000
6303	015	3550	0000	0000
6304	076	0000	6310	0000
6305	001	1476	3536	3536
6306	052	0000	0000	0000
6307	016	3170	2676	2715
6310	015	3550	7722	0000
6311	076	0000	2717	0000
6312	052	0000	0017	0000
6313	016	2717	2676	2715
6314	015	3550	7722	0000
6315	036	0000	6250	0000
6316	~~052~~	~~0000~~	0017	~~0000~~
6317	016	3105	3066	6302
6320	052	0000	0003	0000
6321	505	0047	1417	1423
6322	112	0005	6321	0001
6323	702	0030	1420	0047
6324	112	0010	6323	0001
6325	005	1417	1417	1431
6326	002	0252	1431	1432
6327	015	7761	1431	0000
6330	036	0000	6333	0000
6331	044	1432	0000	1432
6332	056	0000	2617	0000
6333	004	0053	0052	1420

6334	005	1420	1420	0055	
6335	001	7761	0055	0055	
6336	044	0055	0000	0055	
6337	004	7761	0055	0056	
6340	005	1420	0056	0055	
6341	002	0000	0055	0055	
6342	056	0000	2622	0057	
6343	000	0000	0000	0000	
6344	054	0044	1440	1437	
6345	072	0000	1437	0000	
6346	400	0000	0000	1420	
6347	400	0001	0000	1421	
6350	400	0002	0000	1422	
6351	400	0003	0000	1423	
6352	456	0004	6210	1424	
6353	016	6334	7501	7610	
6354	000	0006	0150	0206	
6355	075	1432	1420	1433	de
6356	000	0000	0000	0000	dm
6357	013	6355	7721	6355	
6360	072	0000	1440	0000	dτ
6361	016	6362	6346	6354	
6362	013	6335	7721	6355	
6363	054	0114	1440	1437	
6364	016	6365	6345	6356	
6365	033	6355	7721	6355	
6366	033	6335	7721	6355	
6367	003	1417	0000	1420	
6370	015	1433	7761	0000	
6371	076	0000	6732	6356	
6372	056	3551	6212	6627	
6373	005	3567	1433	1422	
6374	002	7761	1433	1421	
6375	005	1476	1421	1421	
6376	005	7764	1421	1421	
6377	001	1421	1422	1421	
6400	044	1421	0000	6627	
6401	000	0000	0000	0000	
6402	005	2601	0313	1422	
6403	016	6404	7501	7610	
6404	075	1422	0003	1423	
6405	005	7762	3547	2652	
6406	004	7756	7762	2653	
6407	005	2653	3547	2653	
6410	056	2635	2640	6405	
6411	000	1566	0000	1423	
6412	000	1573	0000	1424	
6413	000	1606	0000	1425	
6414	000	1622	0000	1426	
6415	000	1624	0000	1427	
6416	000	3562	0000	1430	
6417	000	3570	0000	1431	
6420	052	0000	0000	0000	
6421	500	3726	0000	1432	
6422	112	0005	6421	0001	
6423	500	3712	0000	0062	
6424	500	6107	0000	3712	
6425	112	0010	6423	0001	
6426	013	1560	6120	1560	
6427	013	157[illegible]	6120	1575	

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6430	013	1611	6120	1611	
6431	000	6124	0000	1566	
6432	000	6125	0000	1573	
6433	000	6126	0000	1606	
6434	000	6127	0000	1622	
6435	000	6130	0000	3562	
6436	000	6131	0000	3570	
6437	000	0000	0000	1422	
6440	005	1420	7764	0041	
6441	005	0041	0041	0042	
6442	001	7764	0042	0042	
6443	044	0042	0000	0042	
6444	001	0041	0042	0077	
6445	002	0077	1420	0041	
6446	005	0041	0041	0041	
6447	002	0000	0041	0041	
6450	016	6451	7501	7610	
6451	075	0041	0003	0042	
6452	000	0000	0000	0000	
6453	005	0042	0077	0043	
6454	000	1420	0000	0041	
6455	016	6456	6446	6452	
6456	000	0000	0000	6452	
6457	016	6460	7501	7610	
6460	075	1420	0031	0041	
6461	001	7761	0041	0041	
6462	005	0041	0414	0041	
6463	056	0041	6165	0077	
6464	000	0000	0000	0000	
6465	002	1421	0251	3727	
6466	002	0000	0251	3730	
6467	000	0000	0000	0000	
6470	002	0041	3726	3731	
6471	001	0251	0251	3732	
6472	001	0251	0251	3733	
6473	016	6474	1550	1624	
6474	000	1423	0000	1566	
6475	000	1424	0000	1573	
6476	000	1425	0000	1606	
6477	000	1426	0000	1622	
6500	000	1427	0000	1624	
6501	000	1430	0000	3562	
6502	000	1431	0000	3570	
6503	052	0000	0000	0000	
6504	500	1432	0000	3725	
6505	112	0005	6504	0001	
6506	056	0000	6140	1420	
6507	452	0000	0000	6512	
6510	100	0000	0000	4000	
6511	112	2114	6510	0001	
6512	000	0000	0000	0000	
6513	000	0000	0000	0000	
6514	056	0000	1514	0000	
6515	000	0000	0000	0000	
6516	000	0000	0000	0000	
6517	000	0000	0000	0000	
6520	000	0000	0000	0000	
6521	000	0000	0000	0000	
6522	000	0000	0000	0000	
6523	000	0000	0000	0000	
6524	000	0000	0000	0000	
6525	000	0000	0000	0000	
6526	000	0000	0000	0000	
6527	000	0000	0000	0000	
6530	056	0000	6553	0000	
6531	050	0012	0001	0023	
6532	070	0001	6531	0000	
6533	016	6534	0006	0022	
6534	000	0000	0000	0022	
6535	016	6536	3113	3150	
6536	000	3357	0000	3150	
6537	050	0411	2101	2600	
6540	070	2101	6537	0000	
6541	016	6542	1514	4635	
6542	056	0000	4272	4635	
6543	050	0012	4000	6114	
6544	070	4000	6543	0000	
6545	000	0000	0000	0000	
6546	000	0000	0000	0000	
6547	000	3720	0000	0041	
6550	000	3721	0000	3720	
6551	000	3722	0000	3721	
6552	056	0041	1543	3722	
6553	005	3504	3504	1432	
6554	072	0000	0000	0000	
6555	100	0000	0000	0060	
6556	112	0012	6555	0001	
6557	056	0000	6531	0000	
6560	000	0000	0000	0000	
6561	000	0000	0000	0000	
6562	000	6566	0000	6644	
6563	072	0000	0000	0000	
6564	452	0000	0000	6577	
6565	452	0000	0000	6571	
6566	401	4001	6624	6624	
6567	112	0011	6566	0001	
6570	013	6566	3354	6566	
6571	000	0000	0000	0000	
6572	112	0011	6565	0001	
6573	016	6574	7501	7610	
6574	052	6624	0041	6635	
6575	013	6644	3471	6644	
6576	056	6644	2023	6566	
6577	000	0000	0000	0000	
6600	112	0012	6564	0001	
6601	000	6643	0000	6566	
6602	000	0000	0000	0000	
6603	000	3265	0000	6567	
6604	000	3266	0000	6570	
6605	016	6606	6562	6602	
6606	000	3267	0000	6567	
6607	056	3270	3145	6570	
6610	000	0000	0000	0000	
6611	000	0000	0000	0000	
6612	000	0000	0000	0000	
6613	000	0000	0000	0000	
6614	000	0000	0000	0000	
6615	000	0000	1000	0000	N_{z*}
6616	000	0000	0000	0000	$n(\bar{n})$
6617	000	0000	0000	0000	$n(d_o)$

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6620	000	0000	0000	0000	$n(\beta_0)$
6621	000	0000	0000	0000	$n(H)$
6622	000	0000	0000	0000	$n(\alpha_*)$
6623	000	0000	0000	0000	
6624	000	0000	0000	0000	
6625	000	0000	0000	0000	
6626	000	0000	0000	0000	
6627	000	0000	0000	0000	
6630	000	0000	0000	0000	
6631	000	0000	0000	0000	
6632	000	0000	0000	0000	
6633	000	0000	0000	0000	
6634	000	0000	0000	0000	
6635	000	0000	0000	0000	
6636	000	0000	0000	0000	
6637	000	0000	0000	0000	
6640	000	0000	0000	0000	
6641	000	0000	0000	0000	
6642	000	0000	0000	0000	
6643	000	0000	0000	0000	
6644	000	0000	0000	0000	
6645	000	0000	0000	0000	
6646	003	6745	6750	6631	
6647	016	6650	7501	7610	
6650	000	6631	0004	6631	
6651	002	0000	6631	6631	
6652	000	0000	0000	0000	
6653	000	0000	0000	0000	
6654	000	0000	0000	0000	
6655	000	0000	0000	0000	
6656	000	0000	0000	0000	
6657	000	0000	0000	0000	
6660	000	0000	0000	0000	
6661	000	0000	0000	0000	
6662	000	0000	0000	0000	
6663	000	0000	0000	0000	
6664	000	0000	0000	0000	
6665	000	0000	0000	0000	
6666	000	0000	0000	0000	
6667	000	0000	0000	0000	
6670	000	0000	0000	0000	
6671	000	0000	0000	0000	
6672	000	0000	0000	0000	
6673	000	0000	0000	0000	
6674	000	0000	0000	0000	
6675	000	0000	0000	0000	
6676	354	0107	0000	0002	
6677	715	0000	0002	0003	Transducer
6700	354	0045	0000	0002	for uni-
5701	707	0002	0000	0000	formly

distributed random numbers

6702	713	0001	0000	0002	
6703	521	0002	0000	0002	
6704	000	0000	0000	0000	
6705	300	0000	0000	0000	
6706	000	0000	0000	0000	
6707	002	2675	2602	2601	
6710	056	0000	6402	0000	
6711	005	1423	1437	1437	
6712	056	0000	3677	0000	
6713	545	0413	2636	2075	
6714	100	0000	0000	0000	
6715	075	4132	6362	0750	
6716	130	3360	3661	0707	Constants
6717	100	0000	0000	0000	for draw-
6720	077	6740	7542	1616	ing ξ^{v*}_{KL}
6721	620	4757	4005	7356	
6722	100	0000	0000	0000	
6723	100	4257	4005	7356	
6724	771	3636	0576	7024	
6725	100	0000	0000	0000	R_1
6726	077	7474	1375	6050	
6727	367	7305	3574	6742	
6730	100	0000	0000	0000	R_2
6731	100	7305	3574	6742	
6732	377	7313	0013	7566	
6733	100	0000	0000	0000	R_7
6734	100	7313	0013	7566	
6735	060	6153	0513	2322	
6736	100	0000	0000	0000	R_3
6737	100	6153	0513	2322	
6740	012	6714	0665	6475	
6741	100	0000	0000	0000	R_4
6742	100	6714	0665	6475	
6743	453	4165	6507	0167	
6744	100	0000	0000	0000	R_5
6745	100	4165	6507	0167	
6746	074	3552	7726	1403	
6747	100	0000	0000	0000	R_6
6750	077	7325	7654	3006	
6751	052	0000	6735	0000	
6752	016	6753	6676	6704	
6753	000	6737	0000	6632	
6754	052	0000	6740	0000	
6755	016	6756	6676	6704	
6756	000	6742	0000	6633	
6757	052	0000	6743	0000	
6760	016	6761	6676	6704	
6761	052	0000	6744	0000	
6762	016	6646	6676	6704	
6763	000	0000	0000	0000	

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NUMERICAL INFORMATION FOR BLOCK I (0)

0100	++03	100000000	
0101	++03	101000000	
0102	++03	102000000	
0103	++03	160000000	H_0
0104	++03	200000000	
0105	++03	300000000	
0106	++03	500000000	
0107	++04	150000000	
0110	++04	700000000	
0111	++06	700000000	
0112	++04	781000000	V_∞ [m/s]
0113	++04	778600000	
0114	++04	772800000	
0115	++04	761500000	
0116	++04	112837900	
0117	++04	112837900	
0120	++04	112837900	
0121	++03	954700000	$\bar{V}$ [m/s]
0122	++04	106300000	
0123	++04	117200000	
0124	++04	135100000	
0125	++04	100000000	
0126	++04	100000000	
0127	++04	100000000	T_∞ [°K]
0130	++04	120700000	
0131	++04	140400000	
0132	++04	142300000	
0133	++04	157600000	
0134	++00	600000000	
0135	++00	575000000	
0136	++00	540000000	
0137	++00	500000003	d_{e1}
0140	++00	445000000	
0141	++00	362000000	
0142	++00	240000000	
0143	++00	900000000	
0144	++00	890000000	
0145	++00	870000000	
0146	++00	840000000	d_{e2}
0147	++00	795000000	
0150	++00	730000000	
0151	++00	630000000	
0152	++01	148000000	
0153	++01	146000000	
0154	++01	136000000	
0155	++01	124000000	d_{n1}
0156	++01	110000000	
0157	++00	940000000	
0160	++00	780000000	
0161	++01	120000000	
0162	++01	117500000	
0163	++01	111000000	
0164	++00	980000000	d_{n2}
0165	++00	800000000	
0166	++00	565000000	
0167	++00	300000000	
0170	++00	000000000	
0171	++00	275000000	$d_{\tau 1}$

0172	++00	540000000	
0173	++00	775000000	$d_{\tau 1}$
0174	++01	100000000	
0175	++01	121000000	
0176	++01	136000000	
0177	++00	000000000	
0200	++00	145000000	
0201	++00	290000000	
0202	++00	445000000	$d_{\tau 2}$
0203	++00	575000000	
0204	++00	665000000	
0205	++00	700000000	
0206	++00	000000000	
0207	++00	258800000	
0210	++00	500000000	
0211	++00	707100000	$\sin\theta_1$
0212	++00	866000000	
0213	++00	965900000	
0214	++01	100000000	
0215	+-01	400000000	
0216	+-01	821000000	
0217	++00	128400000	
0220	++00	222470000	
0221	++00	392700000	Ψ
0222	++00	609010000	
0223	++00	778554000	
0224	++00	871980000	
0225	++00	919760000	
0226	++00	945818000	
0227	++00	961220000	
0230	-+01	455000000	
0231	-+01	300000000	
0232	-+01	200000000	
0233	-+01	100000000	
0234	++00	000000000	
0235	++01	100000000	S_{23}
0236	++01	200000000	
0237	++01	300000000	
0240	++01	400000000	
0241	++01	500000000	
0242	++01	600000000	
0243	++01	100000000	
0244	++01	100000000	
0245	+-03	100000000	ε_2
0246	++01	455000000	
0247	++01	152300000	
0250	++03	400000000	T_w [°K]
0251	++01	325000000	
0252	++01	100000001	
0253	++00	000000000	N_{1p}
0254	++00	000000000	N_{2p}
0255	+-04	100000000	ε_1
0256	++00	000000000	N_{3p}
0257	++02	100000000	
0260	++00	000000000	
0261	++00	000000000	
0262	++00	000000000	
0263	++00	000000000	d_0 [deg]

0264	++00	000000000		0342	++00	000000000	I_{22}
0265	++00	000000000	α_0[deg]	0343	++00	000000000	I_{13}
0266	++00	000000000		0344	++00	000000000	I_{23}
0267	++00	000000000		0345	++15	100000000	L_1
0270	++00	000000000		0346	++14	100000000	L_2
0271	++00	000000000		0347	++00	000000000	
0272	++00	000000000		0350	++00	000000000	
0273	++00	000000000		0351	++00	000000000	
0274	++00	000000000		0352	++00	000000000	
0275	++00	000000000		0353	++00	000000000	
0276	++00	000000000		0354	++00	000000000	
0277	++00	000000000		0355	++00	000000000	
0300	++00	000000000		0356	++00	000000000	
0301	++00	000000000		0357	++00	000000000	
0302	++00	000000000	β_0[deg]	0360	++00	000000000	
0303	++00	000000000		0361	++00	000000000	
0304	++00	000000000		0362	++00	000000000	
0305	++00	000000000		0363	++00	000000000	
0306	++00	000000000		0364	++00	000000000	
0307	++00	000000000		0365	++00	000000000	
0310	++00	000000000		0366	++00	000000000	
0311	++00	000000000	H	0367	++00	000000000	
0312	++00	000000000		0370	++00	000000000	
0313	++00	000000000		0371	++00	000000000	
0314	++00	000000000	α_*	0372	++00	000000000	
0315	++00	000000000		0373	++00	000000000	
0316	++00	000000000	I'_{T1}	0374	++00	000000000	
0317	++00	000000000	I''_{T1}	0375	++00	000000000	
0320	++00	000000000	I_{T2}	0376	++00	000000000	
0321	++00	000000000	I''_{T2}	0377	++00	000000000	
0322	++00	000000000	I_{T3}	0400	++00	000000000	
0323	++00	000000000	I_{T3}	0401	++00	000000000	
0324	++00	000000000		0402	++00	000000000	
0325	++00	564189580	$1/\sqrt{\pi}$	0403	++00	000000000	
0326	+-09	100000000		0404	++00	000000000	
0327	++00	000000000		0405	++00	000000000	
0330	++00	000000000		0406	++00	000000000	
0331	-++01	100000000		0407	++00	000000000	
0332	++00	000000000		0410	++00	000000000	
0333	++00	000000000	N_{4P}	0411	++01	350000000	
0334	++00	000000000	P_0	0412	++01	471238898	$3\pi/2$
0335	++00	000000000	S_M	0413	++01	141421356	$\sqrt{2}$
0336	++00	000000000	α_M	0414	++01	177245384	$\sqrt{\pi}$
0337	++00	000000000	I_{11}	0415	++00	886227000	
0340	++00	000000000	I_{21}	0416	++01	628318531	2π
0341	++00	000000000	I_{12}	0417	++01	314159265	π

BLOCK II (M)

```
2001 015 3550 6615 0000          2003 056 0000 3043 0000
2002 036 0000 3064 0000          2004 000 0000 0000 0000

2513 056 1420 3632 2602

2635 056 0000 2640 0000          2644 005 1423 1422 1422
2636 005 1437 1437 1435          2645 005 1423 1424 1424
2637 000 0000 0000 0000          2646 005 1423 1435 1435
2640 004 2652 1476 1425          2647 001 1422 1425 1433
2641 016 2642 6646 2637          2650 001 1424 1427 1434
2642 002 1433 1425 1422          2651 056 6167 2661 1416
2643 002 1434 1427 1424

2661 002 1433 1435 1422          2666 036 0000 6746 0000
2662 004 1434 1422 1424          2667 016 2670 7501 7610
2663 002 1424 0215 0000          2670 000 0012 0150 0215
2664 036 0230 6756 1420          2671 075 1424 0230 1420
2665 002 0227 1424 0000          2672 056 0000 6756 0000

3040 001 7761 2675 2675          3042 056 0000 2001 0000
3041 013 3550 7722 3550

6373 002 0313 0000 0000          6376 036 0000 6572 0000
6374 036 0000 6402 0000          6377 004 1422 0313 1423
6375 002 0313 2601 1422          6400 056 0000 6405 0000

6646 004 2653 1476 1427          6651 002 1432 1435 1437
6647 002 7761 1433 1433          6652 005 1436 1436 1434
6650 002 1434 1420 1436          6653 056 0000 2636 0000
6710 056 0000 6373 0000
6732 002 2602 2675 0000          6734 016 2651 6647 2637
6733 036 7761 6707 1423

6746 005 1424 0314 1425          6755 044 1420 0000 1420
6747 001 1425 0334 1425          6756 044 1423 0000 1423
6750 044 1425 0000 1425          6757 000 1420 0000 0041
6751 001 0315 1425 1425          6760 016 6761 6455 6167
6752 002 7761 1424 1426          6761 044 1434 0000 1436
6753 005 7762 1426 1426          6762 005 7762 0041 0041
6754 004 1425 1426 1420          6763 056 1416 6711 6167

0314 002 0540 0000 0300 Number   0315 001 0520 0000 0000 Number
                         16                                1,5
0332 001 0400 0000 0000 Number   0534 202 0467 2400 0000 Number
                         1,0                               -13,75
```

Note: introduce data into cells 0313,1420,5222-5242

DOC = 83067305 PAGE 261

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BLOCK III (U)

```
2513 056 0000 3632 0000

2601 030 3000 0011 0300
2602 175 1476 6775 6373

2635 076 0000 2640 6356

2641 016 6402 6646 2637

2644 005 1422 6373 1422
2645 005 1424 6374 1424
2646 005 1435 6375 1435

6373 052 7032 0000 7615 }PП
6374 000 7504 0000 7541 }
6375 016 6376 7501 7610
6376 052 6764 0042 7031
6377 052 7032 0000 7615 }PП
6400 000 7504 0000 7541 }
```

```
6401 056 2635 2640 6371
6402 052 0000 0000 0000
6403 016 6404 7501 7610
6404 000 0010 0150 6764
6405 175 1476 6775 6373
6406 013 6405 2601 6405
6407 112 0002 6403 0001
6410 056 2602 2642 6405

6707 005 2653 3547 2653
6710 056 0000 6373 0000
6711 005 6375 1437 1437

6732 005 7762 3547 2652
6733 054 7756 7762 2653
6734 056 0000 6707 0000

6756 044 6375 0800 6375
```

BLOCK IV (U)

```
2717 056 0000 3037 0000

3064 056 0000 6250 0000

3122 000 0000 0000 0000

3130 504 4001 1433 4001
3131 504 4232 1434 4232
3132 112 0230 3130 0001
3133 052 0000 0000 0000
3134 505 4001 0331 4001
3135 112 0210 3134 0021
3136 056 0000 3625 0000
3137 112 0000 3140 0001
3140 400 4001 0000 4463
3141 400 4022 0000 4464
3142 400 4043 0000 4465
3143 400 4232 0000 4466
3144 456 4253 3577 4467

3577 400 4274 0000 4470
3600 400 4064 0000 4471
3601 400 4105 0000 4472
3602 400 4126 0000 4473
3603 400 4315 0000 4474
3604 400 4336 0000 4475
3605 400 4357 0000 4476
3606 400 4147 0000 4477
3607 400 4170 0000 4500
3610 400 4211 0000 4501
3611 400 4400 0000 4502
3612 400 4421 0000 4503
3613 400 4442 0000 4504
3614 452 0000 0030 3520
3615 701 4463 4471 4505
3616 701 4505 4477 4505
3617 112 [illegible] 3615 0001
```

```
3620 000 0000 0000 0000
3621 016 3622 7501 7610
3622 052 4463 0041 4512
3623 112 0000 3140 0001
3624 056 3137 3145 3623
3625 052 0000 0000 0000
3626 054 0114 6616 0001
3627 013 3625 0001 3623
3630 033 3623 7724 3523
3631 056 0000 3140 0000

5346 056 0000 5706 0000

5715 054 0114 7724 1437
5716 056 1437 6022 1436
5717 053 5020 1436 5020
5720 053 1437 1436 1436
5721 056 0000 6164 0000

6063 456 5222 6017 5020

6254 056 0050 1440 0001
6255 033 0001 7722 0001
6256 072 0000 0001 0000
6257 016 3170 3645 3653

6275 016 3667 3066 6302

6300 032 0000 6317 0017

6304 076 0000 6312 0000

6307 016 6254 2676 2715

6313 016 3663 2676 2715

6317 016 3673 3066 6302
```

BLOCK V (B)

1532	001	0043	0343	0050
1533	056	0000	3200	0000
1534	001	0043	0343	0050
1535	056	0000	3224	0000
1536	005	0002	0002	0002
1537	005	0001	3263	0001
1540	056	0000	3171	0000
3106	000	0000	0000	0000
3107	056	0000	3111	3550
3110	056	0000	3111	0300
3170	056	0000	2717	0000
3171	005	0002	3264	0002
3172	001	0001	0002	0001
3173	002	7761	0001	0000
3174	036	0000	3176	0000
3175	056	0000	3200	0000
3176	001	7761	3271	3271
3177	056	0000	1554	0300
3200	001	7761	3272	3272
3201	056	0000	1633	0000
3224	002	0047	3235	0001
3225	002	0050	3236	0002
3226	005	0001	0001	0001
3227	056	0000	1536	0000
3230	001	0341	0342	3235
3231	001	0343	0344	3236
3232	004	3235	7762	3235
3233	004	3236	7762	3236
3234	056	0000	5104	0000
3257	004	3517	3272	1420
3260	005	1420	3262	1420
3261	056	0000	5114	0000
3271	000	0000	0000	0000
3272	000	0000	0000	0000
4000	056	4517	4123	0026
4001	015	3344	7724	0000
4002	036	4006	4005	1632
4003	015	3344	7722	0000
4004	036	4007	4005	1632
4005	056	0000	4050	0000
4006	056	0000	1532	0000
4007	056	0000	1534	0000
4011	456	0313	4016	3503
4012	056	4515	4066	4104
4013	056	C300	4174	4071
4014	056	0000	4015	4111
4015	056	4516	4000	0025
4174	000	0025	0000	4516
4175	056	0026	4267	4517
4267	000	0000	0000	0025
4270	000	0000	0000	0026
4271	056	4514	4117	4104
4477	076	5011	4506	4553
4502	056	4505	4506	4553
4506	015	0000	3344	0000
4507	076	5114	4511	3113
4510	056	5012	4050	1632
4511	056	4012	3230	4052
4512	000	4013	0000	4116
4513	056	4014	4001	4122
4514	001	0043	0044	0046
4515	000	0000	0000	0046
4516	000	0000	0000	0000
4517	000	0000	0000	0000
4520	056	0000	4537	0000
4547	052	5501	0041	5671
4551	016	4552	7501	7610
4552	052	3271	0041	3272
4560	000	0000	0000	0000
4561	000	0000	0000	0000
4656	000	0000	0000	3271
4657	000	0000	0000	3272
5012	001	0043	0343	0050
5104	005	0243	0243	0001
5105	005	0244	0244	0002
5106	004	7761	0001	3263
5107	004	7761	0002	3264
5110	005	0243	0244	0001
5111	005	0417	0001	3262
5112	004	3262	0024	3262
5113	056	5115	5114	5113
5114	004	3517	3521	1420
5115	056	0000	3257	0000
5116	015	7722	3344	0000
5117	036	0000	4512	0000
5120	015	7724	3344	0000
5121	036	7761	4512	3262

Note: introduce data into cells 0243,0244,3344

BLOCK VI (K)

```
1504 056 0000 6633 0000

1532 001 0043 0343 0050
1533 056 0000 3035 0000
1534 001 0043 0343 0050
1535 056 0000 3224 0000

2527 056 0000 2720 2524

2717 056 0000 3037 0000
2720 054 0034 1440 0001
2721 015 0001 0000 0003
2722 036 0000 2530 0000
2723 000 0000 0000 0000
2724 000 0000 0000 0000
2725 000 2544 0000 0001
2726 000 2600 0000 0002
2727 000 3346 0000 2544
2730 016 2731 3171 2500
2731 000 0001 0000 2544
2732 000 0002 0000 2600
2733 005 1417 0051 5000
2734 015 5000 0000 0000
2735 036 7761 3001 4777
2736 016 2737 7501 7610
2737 052 1430 0033 0065
2740 052 1420 0000 0003
2741 004 7761 5000 5000
2742 005 1476 5000 5006
2743 452 0000 0000 2750
2744 505 1420 5000 5001
2745 705 5001 1420 5005
2746 505 1420 5004 5013
2747 112 0002 2744 0001
2750 000 0000 0000 0000
2751 005 5001 1421 5010
2752 005 5002 1422 5011
2753 005 5001 1422 5012
2754 054 0030 1440 0001
2755 031 0001 7722 0001
2756 072 0000 0001 0000
2757 002 1417 0000 0000
2760 036 0000 2766 0000
2761 301 4777 4001 4001
2762 013 2761 2773 2761
2763 015 2761 2774 0000
2764 075 0000 2761 0000
2765 056 2776 3000 2761
2766 301 4777 4021 4021
2767 013 2766 2773 2766

3066 056 0000 3014 0000

3106 000 0000 0000 0000
3107 056 0000 3111 3550

3122 000 0000 0000 0000
```

```
1536 005 0002 0002 0002
1537 005 0001 3263 0001
1540 056 0000 3026 0000

2770 015 2766 2775 0000
2771 076 0000 2766 0000
2772 056 2777 3000 2766
2773 000 0001 0040 0040
2774 301 5016 4741 4741
2775 301 5016 4761 4761
2776 301 4777 4001 4001
2777 301 4777 4021 4021
3000 000 0000 0000 0000
3001 000 6525 0000 0046
3002 000 6526 0000 0047
3003 000 6527 0000 0050
3004 000 0000 0000 0000
3005 056 0000 7030 0000
3006 000 6525 0000 3011
3007 000 6526 0000 3012
3010 056 6527 6271 3013
3011 000 0000 0000 0000
3012 000 0000 0000 0000
3013 000 0000 0000 0000
3014 502 3522 6522 3522
3015 000 3011 0000 6525
3016 000 3012 0000 6526
3017 056 3013 3067 6527
3020 000 0040 0040 0020
3021 000 0000 0000 0000
3022 000 0020 0000 0000
3023 000 0000 0020 0000
3024 000 0000 0000 0020
3025 000 0040 0000 0000
3026 005 0002 3264 0002
3027 001 0001 0002 0001
3030 002 7761 0001 0000
3031 036 0000 3033 0000
3032 056 0000 3035 0000
3033 031 7761 6606 6606
3034 056 0000 1554 0000
3035 031 7761 6607 6607
3036 056 0000 1633 0000
3037 056 0000 3006 0000

3110 056 0000 3111 0000
```

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```
3127 003 3504 7757 0300
3130 076 3521 3132 1421
3131 056 3517 2101 1420

3132 005 3517 3515 1420
3133 056 0000 2101 0000

3170 056 0000 2717 0000
3171 000 0370 0000 0070

3172 001 0245 0070 0070
3173 056 0000 2531 0000

3224 002 0047 3235 0001
3225 002 0050 3236 0002
3226 005 0001 0001 0001
3227 056 0000 1536 0000
3230 001 0341 0342 3235
3231 001 0343 0344 3236
3232 004 3235 7762 3235

3233 004 3236 7762 3236
3234 056 0000 5104 0000
3235 000 0000 0000 0000
3236 000 0000 0000 0000
3237 004 3517 6607 1420
3240 005 1420 3262 1420
3241 056 0000 3114 0000

4000 056 4517 4123 0026
4001 015 3344 7724 0000
4002 036 4006 4005 1632
4003 015 3344 7722 0000
4004 036 4007 4005 1632
4005 056 0000 4050 0300
4006 056 0000 1532 0000

4007 056 0000 1534 0000
4010 072 0000 6614 0000
4011 456 0313 4016 3503
4012 056 4515 4066 4104
4013 056 0000 4174 4071
4014 056 0000 4015 4111
4015 056 4516 4000 0025

4174 000 0025 0000 4516

4175 056 0026 4267 4517

4267 000 0000 0000 0025
4270 000 0000 0000 0026

4271 056 4514 4117 4104

4476 003 3504 7757 0300
4477 076 5011 4506 6553
4500 000 4503 0000 4130
4501 000 4504 0000 3116
4502 056 4505 4506 6553
4503 000 7761 0000 0041
4504 004 3510 7762 1437
4505 005 3510 3510 1432
4506 015 3344 0000 0000

4507 076 5116 4511 3113
4510 056 5012 4050 1632
4511 056 4012 3230 4052
4512 000 4013 0000 4116
4513 056 4016 4001 4122
4514 001 0043 0044 0046
4515 000 0000 0000 0046
4516 000 0000 0000 0000
4517 000 0000 0000 0000

4520 056 0000 4537 0000

4547 052 3501 0041 5671

4560 000 0000 0000 0000

4561 000 0000 0000 0000

4656 000 0000 0000 6606

4657 000 0000 0000 6607

4710 056 3516 5013 5517

5012 001 0043 0343 0350
5013 015 3514 0000 0300
5014 076 0000 4711 0000

5015 000 0000 0000 4711
5016 056 5017 4711 4345
5017 100 0000 0000 1417

5104 005 0243 0243 0001
5105 005 0244 0244 0002
5106 004 7761 0001 3263
5107 004 7761 0002 3264
5110 005 0243 0244 0001
5111 005 0417 0001 3262
5112 004 3262 0024 3262

5113 056 5115 5116 3113
5114 004 3517 3521 1420
5115 056 0000 3237 0000
5116 015 7722 3344 0000
5117 036 0000 4312 0000
5120 015 7724 3344 0000
5121 036 7761 4312 3262
```

5330	056	0000	5706	0000
5331	015	3344	0000	0000
5332	036	0000	2105	0000
5333	005	1420	3262	1420
5334	030	6537	0000	1421
5335	004	1420	1421	1422
5336	005	3510	1422	1423
5337	004	1422	3510	1424
5340	005	7762	7765	1427
5341	005	1427	1424	1425
5342	004	1424	3510	1426
5343	032	0000	2334	0000
5344	504	4001	1421	4001
5345	505	4041	1423	4041
5346	505	4241	1425	4241
5347	112	0037	2114	0001
5350	032	0000	2255	0000
5351	505	4101	1422	4101
5352	505	4301	1424	4301
5353	505	4441	1424	4441
5354	505	4601	1426	4601
5355	112	0137	2121	0001
5356	452	0000	0000	2132
5357	701	4041	4061	4741
5360	112	0017	2127	0001
5361	013	2127	3020	2127
5362	000	0000	0000	0000
5363	112	0155	2126	0001
5364	000	0000	0000	0000
5365	052	0000	0000	0000
5366	415	4741	0000	0000
5367	436	4741	2172	0007
5370	704	4761	4741	4761
5371	704	5001	4761	5301
5372	704	5021	4761	5021
5373	704	5041	4761	5341
5374	000	0000	0000	0000
5375	000	0000	0000	0000
5376	605	4761	4761	0001
5377	605	5001	5001	0002
5400	605	5021	5021	0003
5401	001	0001	0002	0004
5402	101	0004	0003	5521
5403	205	1427	5521	0004
5404	502	5041	0004	5041
5405	605	4761	5001	0004
5406	605	5001	5021	0005
5407	605	4761	5021	0006
5410	452	0000	0000	2163
5411	505	0001	0007	0001
5412	112	0005	2161	0001
5413	000	0000	0000	0000
5414	502	5061	0001	5301
5415	504	5101	0002	5321
5416	502	5121	0003	5341
5417	502	5141	0004	5361
5420	502	5161	0005	5401
5421	502	5201	0006	5421
5422	112	0017	2136	0001
5423	000	0000	0000	0000

5424	000	0000	0000	0000
5425	052	0000	0000	0000
5426	605	5301	4761	0001
5427	605	5361	5001	0002
5430	605	5421	5021	0003
5431	001	0001	0002	0004
5432	001	0004	0003	0004
5433	005	7762	0004	0004
5434	601	4261	4261	0005
5435	004	0005	1427	0005
5436	205	0005	4761	0005
5437	402	5221	0004	0002
5440	102	0002	0005	5441
5441	112	0017	2176	0001
5442	013	2207	3022	2207
5443	013	2206	3023	2206
5444	013	2210	3024	2210
5445	000	0000	0000	0000
5446	013	2176	3025	2176
5447	013	2176	3022	2176
5450	033	2177	3025	2177
5451	033	2200	3022	2200
5452	016	2223	2175	2215
5453	013	2176	3025	2176
5454	013	2177	3025	2177
5455	013	2177	3022	2177
5456	033	2200	3025	2200
5457	016	2230	2175	2215
5460	036	0000	2236	0000
5461	000	0000	0000	0000
5462	000	0000	0000	0000
5463	000	0000	0000	0000
5464	000	0000	0000	0000
5465	000	0000	0000	0000
5466	000	0000	0000	0000
5467	000	0000	0000	0000
5470	000	0000	0000	0000
5471	000	0000	0000	0000
5472	000	0000	0000	0000
5473	052	0000	0000	0000
5474	415	4041	0000	0000
5475	036	0000	2253	0000
5476	704	4101	4041	4101
5477	704	4141	4041	4141
5500	704	4201	4041	4201
5501	504	4241	1427	4241
5502	000	0000	0000	0000
5503	112	0037	2244	0001
5504	032	0000	2267	0000
5505	452	0000	0000	2260
5506	302	0000	4061	4061
5507	112	0017	2255	0001
5510	000	0000	0000	0000
5511	013	2256	2265	2256
5512	112	0015	2255	0001
5513	056	2264	2266	2256
5514	302	0000	4061	4061
5515	000	0000	0040	0040
5516	032	0000	2121	0000
5517	505	4001	0331	4001

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5520	112	1520	2267	0020
5521	054	0130	6137	1431
5522	013	2351	1431	2351
5523	013	3022	6137	1432
5524	052	0000	0000	0000
5525	544	5521	0000	5521
5526	705	4741	5041	5541
5527	112	0017	2275	0001
5530	000	0000	0000	1430
5531	052	0000	0000	0000
5532	100	0000	0000	2500
5533	112	0023	2302	0001
5534	052	0000	0000	0000
5535	452	0000	0000	2313
5536	401	4741	2500	2500
5537	401	5041	2501	2501
5540	401	5541	2502	2502
5541	401	5521	2503	2503
5542	112	0002	2306	0001
5543	000	0000	0000	0000
5544	452	0000	0000	2317
5545	513	2306	2322	2305
5546	112	0003	2315	0001
5547	000	0000	0000	0000
5550	112	0004	2305	0001
5551	032	0000	2327	0000
5552	000	0003	0004	0004
5553	401	4741	2500	2500
5554	401	5041	2501	2501
5555	401	5541	2502	2502
5556	401	5521	2503	2503
5557	500	2323	0000	2306
5560	112	0003	2327	0001
5561	504	2474	7763	2474
5562	112	0027	2331	0001
5563	032	0000	2374	0000
5564	054	0130	6137	1431
5565	013	2341	1431	2341
5566	013	3022	3024	0004
5567	452	0000	0000	2342
5570	704	4041	3242	4041
5571	112	7777	2340	0001
5572	000	0000	0000	0000
5573	013	2340	0004	2340
5574	112	0033	2337	0001
5575	032	0000	2114	0000
5576	452	0000	0000	2364
5577	452	0000	0000	2352
5600	500	4001	0000	4001
5601	112	7777	2350	0001
5602	000	0000	0000	0000
5603	013	2361	6137	2361
5604	013	2350	1432	2350
5605	013	1430	1431	1430
5606	000	0000	0000	0000
5607	112	0016	2347	0001
5610	016	2361	7501	7610
5611	052	4001	0041	4000
5612	013	2361	1430	2361
5613	000	0000	0000	1430
5614	000	0000	0000	0000
5615	112	0002	2346	0001
5616	000	0000	0000	0000
5617	033	2357	2373	2357
5620	013	2365	7724	2365
5621	016	3145	2346	2366
5622	000	0000	0000	0000
5623	000	0005	0000	0000
5624	013	2401	6137	2401
5625	052	0000	0000	0000
5626	705	4741	5521	2101
5627	112	0017	2376	0001
5630	000	0000	0000	0000
5631	000	0000	0000	0000
5632	000	6606	0000	2524
5633	000	6607	0000	2525
5634	016	2405	7501	7610
5635	052	2500	0041	2525
5636	000	0000	0000	0000
5637	000	0000	0000	0000
5640	032	0000	2346	0000

5706	050	0015	0001	6030
5707	070	5331	0000	0000
5710	050	4411	0001	6030
5711	070	5331	5706	0000

6603	016	6604	7501	7610
6604	052	3242	0042	3261
6605	056	0000	2507	0000
6606	000	0000	0000	0000
6607	000	0000	0000	0000

Note: introduce data into cells 0243,0244,3242-326I, 3344,5222-5242,6I37

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BLOCK VII (β)

```
0257 003 0400 0000 0000

2764 056 0000 2771 0000

5336 000 1421 0000 1424

5353 000 0000 0000 0000

5674 000 0000 0000 0000
5675 000 0000 0000 0000

5676 000 0000 0000 0000

5701 000 0000 0000 0000
5702 000 0000 0000 0000

5703 112 0143 5351 0001
```

BLOCK VIII (γ)

```
0257 003 0400 0000 0000

2764 056 0074 2771 0074

5335 000 1420 0000 1423

5676 112 0143 5354 0001

5703 000 0000 0000 0000
```

PROGRAM A

```
2024 100 0000 0000 2101
2025 112 0023 2024 0001

3060 100 0000 0000 2101
3061 112 0023 3060 0001

3267 112 0004 6566 0001

3354 000 0005 0001 0001

6566 401 4001 2101 2101
6567 112 0004 6566 0001

6572 056 0000 6604 0000

6574 052 2101 0041 2124

6603 056 3267 3143 6567

6604 001 7762 7763 0046
6605 504 2101 0046 2101
6606 112 0023 6565 0001
6607 056 0000 6573 0000
```

Note: program A must be added to blocks VII and VIII

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BLOCK IX

Num-ber 10^{-5}

0734	104	0400	0000	0000	1030	112	0126	4426	0001
0735	050	0412	4000	6114	1031	000	7761	0000	5051
0736	070	4000	0050	0000	1032	016	4433	4410	4422
0737	056	0000	1504	0000	1033	000	0000	0000	4422
0740	016	0741	7501	7610	1034	052	0000	0000	0000
0741	052	0100	0042	0734	1035	500	5043	0000	5740
0742	016	0743	7501	7610	1036	500	5035	0000	5743
0743	052	1416	0042	1477	1037	112	0002	4435	0001
0744	056	0734	1371	0054	1040	500	5732	0000	5032
0745	500	0420	0000	4020	1041	112	0126	4440	0001
0746	112	0775	0745	0001	1042	015	5034	0000	0000
0747	056	0737	4350	0052	1043	076	7761	4477	1470
0750	052	0000	0000	0000	1044	002	7761	5050	6001
0751	054	0114	1364	0014	1045	044	6001	0000	5135
0752	013	4742	0014	4742	1046	001	7761	5050	6002
0753	452	0000	0000	4356	1047	044	6002	0000	6002
0754	500	4020	0000	5020	1050	044	5050	0000	5143
0755	112	0013	4354	0001	1051	000	0000	0000	5140
0756	000	0000	0000	0000	1052	004	5050	6002	5136
0757	400	5201	0000	5034	1053	002	0000	5136	5136
0760	452	0000	0000	4741	1054	004	5143	6002	5137
0761	100	0000	0000	5035	1055	002	0000	5137	5137
0762	112	0142	4361	0001	1056	004	7761	6002	5141
0763	100	0000	0000	1275	1057	000	5137	0000	5142
0764	112	0200	4363	0001	1060	004	5135	6002	5145
0765	052	0000	0000	0000	1061	005	5145	5143	5144
0766	702	5023	5020	6001	1062	016	4463	7501	7610
0767	702	5026	5020	6004	1063	052	5135	0036	5035
0770	705	6001	6001	6007	1064	052	1450	0000	0003
0771	705	6004	6004	6012	1065	000	0000	0000	0000
0772	401	6007	5146	5146	1066	000	5137	0000	1444
0773	401	6012	5147	5147	1067	000	5137	0000	1445
0774	112	0002	4366	0001	1070	005	5135	5047	1467
0775	044	5146	0000	5046	1071	002	0000	5145	1447
0776	044	5147	0000	5047	1072	002	5020	1456	1461
0777	504	5776	5046	5032	1073	002	5021	1457	1462
1000	504	6001	5047	5147	1074	002	5022	1460	1463
1001	112	0005	4377	0001	1075	005	5135	5046	1465
1002	605	5027	5144	6001	1076	056	5145	4725	1446
1003	001	6001	5050	5050	1077	015	5034	7724	0000
1004	112	0010	4402	0001	1100	076	0000	4660	0000
1005	005	5050	5050	6001	1101	000	0000	0000	0000
1006	002	0252	6001	6001	1102	000	0000	0000	0000
1007	044	6001	0000	5051	1103	056	0000	4602	0000
1010	052	0000	0000	0000	1104	002	0000	7761	5135
1011	005	5036	5154	6001	1105	044	7762	0000	0014
1012	005	5153	5037	6004	1106	052	0000	0000	0000
1013	005	5037	5152	6002	1107	100	0000	0000	5136
1014	005	5035	5154	6005	1110	112	0007	4507	0001
1015	005	5035	5153	6003	1111	004	0014	7762	5145
1016	005	5036	5152	6006	1112	002	0000	5145	5141
1017	702	6001	6004	6007	1113	000	5145	0000	5142
1020	504	6007	5051	5043	1114	000	5145	0000	5144
1021	112	0002	4417	0001	1115	016	4516	4462	4465
1022	000	0000	0000	0000	1116	000	0000	0000	4465
1023	052	0000	0000	0000	1117	002	5046	5031	6001
1024	500	5035	0000	5735	1120	004	5046	6001	6001
1025	112	0123	4424	0001	1121	005	5047	6001	5052
1026	500	4711	0000	5026	1122	056	0000	4765	6102
1027	500	4717	0000	4711	1123	052	0000	0000	0000

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1124	605	1456	5152	6003
1125	301	6003	6102	6102
1126	112	0002	4524	0001
1127	005	6102	5052	6002
1130	555	1453	6002	6000
1131	555	5147	5052	6003
1132	732	6000	6003	6006
1133	702	5015	6006	1456
1134	705	6000	6000	6011
1135	401	6011	5103	5103
1136	702	5020	1456	6015
1137	705	6015	6015	6020
1140	401	6020	5102	5102
1141	705	6006	5006	6024
1142	401	6024	5101	5101
1143	112	0005	4530	0001
1144	044	5101	0000	5101
1145	044	5102	0000	5102
1146	044	5103	0000	5103
1147	504	6003	5101	6024
1150	504	6012	5132	6027
1151	705	1445	6024	6032
1152	705	1445	6027	6035
1153	705	5027	6024	6040
1154	705	5027	6027	6043
1155	401	6032	5104	5104
1156	401	6035	5105	5105
1157	401	6040	5106	5106
1160	401	6043	5107	5107
1161	112	0010	4547	0001
1162	352	0000	1100	0000
1163	015	4564	7501	7610
1164	575	5104	0006	6001
1165	112	0001	4563	0001
1166	002	5106	0000	0000
1167	376	5142	4571	1445
1170	056	6001	4572	1464
1171	102	0417	5031	1464
1172	302	5107	0030	0000
1173	076	5142	4575	1446
1174	356	6002	4576	1465
1175	307	0417	5032	1465
1176	305	6102	5047	1467
1177	305	5107	5142	1447
1200	002	0000	1447	1447
1201	056	0000	4725	0000
1202	334	5047	5046	5135
1203	305	5135	5135	6001
1204	302	7761	5031	6001
1205	352	0000	0030	0000
1206	100	0000	0000	5136
1207	112	0007	4636	0001
1210	344	6001	0000	5137
1211	302	0000	5137	5143
1212	000	5135	0000	5145
1213	000	7761	0000	5141
1214	316	4615	4462	4465
1215	000	5137	0000	1444
1216	000	5145	0000	1446
1217	005	5044	5137	1447
1220	001	1447	7761	6001
1221	005	6001	5135	1447
1222	002	0000	1447	1447
1223	052	0000	0000	0000
1224	505	1456	6001	1461
1225	702	5020	1461	1461
1226	112	0002	4624	0001
1227	002	7761	5032	0014
1230	005	0014	7762	6001
1231	005	6001	7762	6001
1232	021	6001	7755	6002
1233	002	5001	6002	6003
1234	002	6003	7757	6004
1235	076	0000	4640	1464
1236	005	7756	6002	1465
1237	056	5047	4656	1467
1240	005	0014	0416	6005
1241	016	4642	7501	7610
1242	075	6005	0011	6006
1243	004	6006	5135	6007
1244	316	4645	7501	7610
1245	075	6007	0012	6010
1246	015	6002	0000	0000
1247	376	5047	4651	1467
1250	056	6010	4656	1465
1251	015	7763	6002	0000
1252	076	0000	4655	0000
1253	001	0416	6010	1465
1254	056	0000	4656	0000
1255	001	0417	6010	1465
1256	005	5031	5047	1466
1257	056	0000	4725	4465
1260	056	0000	4777	0000
1261	500	5035	0000	1450
1262	112	0010	4661	0001
1263	500	5007	0000	1450
1264	112	0013	4663	0001
1265	305	5031	5031	5150
1266	304	7761	5132	1425
1267	112	0016	4666	0001
1270	002	7761	5032	6001
1271	005	0416	6001	1465
1272	015	5034	7722	0000
1273	076	0000	4717	1470
1274	002	5031	0000	0000
1275	076	0000	4700	1443
1276	002	0000	5031	1467
1277	056	5734	4725	1447
1300	054	0102	5033	6010
1301	054	0076	6010	6001
1302	005	5047	5031	6002
1303	002	5047	6001	6003
1304	004	6002	6003	1467
1305	005	1467	1467	6004
1306	004	7761	6004	1443
1307	002	0000	1443	1443
1310	052	0000	0000	0000
1311	405	1456	1467	6001
1312	502	5023	6001	1461
1313	112	0002	4711	0001

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1314	001	1467	0034	1466
1315	002	1466	5031	1466
1316	056	0000	4725	1447
1317	002	7761	5033	6001
1320	005	6001	0417	1467
1321	056	5734	4725	1447
1322	000	0000	0000	0002
1323	000	0000	0000	0001
1324	000	0014	0000	0000
1325	013	5733	7722	5733
1326	015	5732	5733	0000
1327	076	0000	4734	1471
1330	001	0330	0000	0000
1331	076	7761	4734	1471
1332	000	5734	0000	1471
1333	000	0000	0000	0000
1334	013	4354	4724	4334
1335	052	0000	0000	0000
1336	500	1440	0000	0420
1337	112	0035	4736	0001

1340	013	4736	3444	4736
1341	000	0000	0000	0000
1342	112	7777	4353	0001
1343	052	6764	0000	7615
1344	000	7504	0000	7541
1345	056	0000	0050	0000
1346	054	0130	4736	6000
1347	013	4750	6000	4750
1350	030	0000	4751	0077
1351	033	6616	4741	6001
1352	054	0114	6001	6002
1353	054	0050	6000	6003
1354	013	4762	6000	4762
1355	013	4762	6003	4762
1356	013	4760	6002	4760
1357	013	4762	3444	4762
1360	112	7776	4757	0001
1361	016	4762	7501	7610
1362	052	0000	0042	0000
1363	056	0000	0050	0000

1365	052	0000	0000	0000
1366	100	0000	0000	5100
1367	112	0010	4766	0001
1370	056	0000	4523	0000
1371	002	0000	7761	5734
1372	021	0330	7753	5732
1373	061	7751	5732	5732
1374	055	5732	7732	5732

1375	000	0000	0000	5733
1376	032	0000	0745	0000
1377	002	5031	0000	0000
1400	076	0000	5002	0000
1401	032	0000	4661	0000
1402	002	5033	0000	0000
1403	076	0000	5001	0000
1404	032	0000	4504	0000

1502	000	0735	0000	0050

1503	056	0736	0740	0051

Note: introduce data into cells 1364, 6616, and 1345
(except for block IX)

APPENDIX 2

CALCULATION EXAMPLES

Example 1

Assignment of numbers and instructions for calculating the aerodynamic coefficients of a complex body (see Fig. 7)

1. Numbers

Address	Number	Address	Number	Address	Number	Parameter
0420	−2	0457	0	0516	0	
0421	−2	0460	2	0517	−11	
0422	0	0461	−2	0520	0	
0423	−3	0462	0	0521	2	
0424	−3	0463	0	0522	−9	
0425	0	0464	−2	0523	0	
0426	−4	0465	2	0524	0	
0427	−2	0466	0	0525	2	
0430	0	0467	−4	0526	0	
0431	0	0470	2	0527	0	
0432	0	0471	0	0332	0	
0433	0	0472	−3	0260	0	α_0
0434	−2	0473	3	0274	0	β_0
0435	0	0474	0	0310	160	H
0436	0	0475	1	0313	1	α_*
0437	−2	0476	0	0334	1	p_0
0440	0	0477	−1	0335	12,5663706	S_M
0441	2	0500	−4	0336	4	d_M
0442	−2	0501	0	0337	−13,01	x^0_{11}
0443	2	0502	0	0340	0,01	x^0_{21}
0444	0	0503	−4	0341	−3	x^0_{12}
0445	2	0504	0	0342	3	x^0_{22}
0446	0	0505	2	0343	−2,01	x^0_{13}
0447	0	0506	−4	0344	2,01	x^0_{23}
0450	−4	0507	2	0317	−3	x''_{T1}
0451	0	0510	0	0250	320	T_w
0452	0	0511	0,5	0253	1000	N_{1p}
0453	−4	0512	0	0254	6000	N_{2p}
0454	2	0513	0	0256	1000	N_{3p}
0455	0	0514	−11	0333	2000	N_{4p}
0456	−4	0515	0			

2. Instructions

Address	Instructions	Address	Instructions
5201	000 0000 0000 0000	6615	000 0000 0100 0000
5202	000 0000 0001 0000	6616	000 0000 0007 0000
5203	000 0000 0001 0000	6617	000 0000 0001 0000
5204	000 0000 0001 0000	6620	000 0000 0001 0000
5205	000 0001 0000 0000	6621	000 000 0001 0000
5206	000 0000 00(0 0001	6622	000 0000 0001 0000
5207	000 0000 0001 0000	1364	000 0000 0006 0000

3. Block II; numbers and instructions to block II

Address	Numbers and instructions	Address	Numbers and instructions
0313	−1	5225	000 0134 0152 0170
1420	10^{m}	5226	000 0134 0152 0170
5222	000 0134 0152 0170	5227	000 0134 0152 0170
5223	000 0134 0152 0170	5230	000 0134 0152 0170
5224	000 0134 0152 0170		

4. Blocks IV, IX, instruction to block IX

Address	Instruction
1345	000 0000 0000 0000

5. Punched card with control sum equal to zero
6. Numbers (without address code)

Position #	Number	Pos. #	Number	Pos. #	Number	Pos. #	Number	Pos. #	Number
1	7	7	−1	13	0	19	0	25	0
2	1	8	0	14	−1	20	0	26	0
3	1	9	0	15	−1	21	0	27	0
4	0	10	1	16	0	22	6,28318531	28	0
5	0	11	0	17	0	23	0	29	0
6	0	12	0	18	−3	24	4	30	0

7. Punched card with control sum equal to zero

Results of calculation of the aerodynamic coefficients of surface 6 with N_p = 2000

Parameter	Calculated values of the parameters	
	without the use of block II	using block II
c_{+6i}	+−− 00 25333314	
	+−− 02 38246653	
	++− 03 43034721	
m_{+6i}	++− 02 16433219	
	+−− 02 29514657	
	++− 01 14184753	
c_{-6i}	+−− 02 52467521	+−− 01 95118551
	++− 03 13349649	+−− 02 63304634
	+−− 02 16996168	+−− 02 38108233
m_{-6i}	++− 03 59884535	++− 02 60868448
	+−− 02 47080428	+−− 01 12316268
	++− 06 10030515	++− 01 16308264
c_{r6i}	+−− 03 23085248	++− 00 00000000
	+−− 05 40420692	++− 00 00000000
	++− 03 18622387	++− 00 00000000
m_{r6i}	++− 04 71240455	++− 00 00000000
	++− 03 42093157	++− 00 00000000
	++− 04 97449755	++− 00 00000000
c_{6i}	+−− 00 25881075	+−− 00 34845169
	+−− 02 36952109	+−− 01 10155128
	+−− 02 10830457	+−− 02 33804760
m_{6i}	++− 02 23134077	++− 02 77301667
	+−− 02 72385769	+−− 01 15267734
	++− 01 14282303	++− 01 30493017

Example 2

Assignment of numbers and instructions for calculating local flows to the inner surface of a cylinder (see Fig. 8)

1. Numbers

Address	Number	Address	Number	Parameter	Address	Number	Parameter
0420	0	0440	1,0	—	0336	2,0	$d_{н}$
0421	0	0441	0	—	0337	−0,01	x_{11}^{0}
0422	0	0442	0	—	0340	3,0	x_{21}^{0}
0423	0	0443	0	—	0341	−1,0	x_{12}^{0}
0424	1,0	0444	1,0	—	0342	1,0	x_{22}^{0}
0425	0	0445	−3,0	—	0343	−1,0	x_{13}^{0}

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Continued

Address	Number	Address	Number	Parameter	Address	Number	Parameter
0426	0	0446	0	—	0344	1,0	x_{23}^{0}
0427	0	0447	0	—	0243	1,0	—
0430	1,0	0310	100	H	0244	1,0	—
0431	0	0107	3048	V_{∞}	0253	1000	N_{1p}
0432	0	0116	574	$\bar{V}$	0254	5000	N_{2p}
0433	0	0125	452	T_{∞}	0256	1000	N_{3p}
0434	0	0313	1,0	α_{*}	0333	5000	N_{4p}
0435	0	0250	300	T_{w}	0330	−2,0	—
0436	0	0334	1,0	p_0	—	—	—
0437	0	0335	3.14159265	S_{M}	—	—	—

2. Instructions

Address	Instructions	Address	Instructions
6616	000 0000 0002 0000	1364	000 0000 0002 0000
6617	000 0000 0001 0000	5201	000 0001 0000 0000
6620	000 0000 0001 0000	5202	000 0000 0001 0000
6621	000 0000 0001 0000	3344	000 0000 0001 0000
6622	000 0000 0001 0000		

3. Blocks V, VIII (with program A) and IX.
4. Punched card with control sum equal to zero

Results of calculation of the flow of particles to the inner surface of a cylinder with $N_p = 5000$

Values of index k	Calculated values of n_{rk}	Values of index k	Calculated values of n_{rk}
1	−++ 01 162410450	11	−++ 01 110155920
2	+++ 01 166203118	12	+++ 01 102991993
3	−++ 01 152718078	13	−++ 01 100126422
4	+++ 01 151453855	14	+++ 00 967551620
5	−++ 01 140244416	15	−++ 00 855457225
6	+++ 01 147071217	16	+++ 00 808259585
7	−++ 01 129624947	17	−++ 00 751790980
8	+++ 01 126759376	18	+++ 00 644753475
9	−++ 01 119342604	19	−++ 00 589970500
10	+++ 01 116561314	20	+++ 00 473662030

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Example 3

Assignment of numbers and instructions for calculating flow parameters in the outlet section of a complex channel (see Fig. 9)

1. Numbers

Address	Number	Address	Number	Address	Number	Parameter
0420	1	0453	0	0506	1	—
0421	1	0454	0	0507	0	—
0422	1	0455	0	0510	0	—
0423	−0,12	0456	2	0511	0	—
0424	0	0457	0	0512	0	—
0425	0	0460	0	0513	0	—
0426	0	0461	0	0310	100	H
0427	−1	0462	0	0107	8000	V_∞
0430	0	0463	0	0313	1	α_*
0431	1	0464	1	0332	0	—
0432	0	0465	−1	0334	1	p_0
0433	0	0466	0	0335	3,14159265	$S_м$
0434	0	0467	1	0336	2	$d_м$
0435	1	0470	0	0337	0	x^0_{11}
0436	1	0471	0	0340	5	x^0_{21}
0437	0	0472	0	0341	−2,0	x^0_{12}
0440	0	0473	1	0342	2,0	x^0_{22}
0441	0	0474	1	0343	−2,0	x^0_{13}
0442	0	0475	0	0344	2.0	x^0_{23}
0443	0	0476	0	0243	2,0	—
0444	0	0477	−1	0244	2,0	—
0445	6,28318531	0500	0	3242	3,14159265	S_λ
0446	0	0501	0	0253	1000	$N_{1\,p}$
0447	5	0502	0	0254	3000	$N_{2\,p}$
0450	0	0503	6,28318531	0256	1000	$N_{3\,p}$
0451	0	0504	0	0333	1000	$N_{4\,p}$
0452	0	0505	1	0250	1000	T_w

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2. Instructions

Address	Instructions	Address	Instructions
6616	000 0000 0002 0000	5202	000 0001 0000 0000
6617	000 0000 0001 0000	5222	000 0000 0000 0000
6620	000 0000 0001 0000	5223	001 0000 0000 0000
6621	000 0000 0001 0000	3344	000 0000 0001 0000
6622	000 0000 0001 0000	6137	000 0000 0000 0001
5201	000 0000 0001 0000		

3. Instructions of transducer of pseudo-random numbers

Address	Instructions	Address	Instructions
6676	3 14 0115.0000.0002	6727	1 00 0631.4552.5460
6677	6 15 0000.0002.0001	6730	0 00 7777.4000.0000
6700	2 55 0001.0001.0001	6731	0 00 0000.0000.0000
6701	0 14 0054.0001.0001	6732	1 00 1553.1637.2470
6702	5 75 0002.0001.0000	6733	0 00 7777.4000.0000
6703	5 21 0000.0000.0002	6734	0 00 0000.0000.0000
6704	0 00 0000.0000.0000	6735	1 00 5462.0414.7660
6713	1 00 5042.7732.6410	6736	0 00 7777.4000.0000
6714	0 00 7777.4000.0000	6737	0 00 0000.0000.0000
6715	0 00 0000.0000.0000	6740	1 00 0766.2410.1200
6716	1 00 2704.4152.0170	6741	0 00 7777.4000.0000
6717	0 00 7777.4000.0000	6742	0 00 0000.0000.0000
6720	0 00 0000.0000.0000	6743	1 00 2021.3542.3620
6721	1 00 0345.5747.7460	6744	0 00 7777.4000.0000
6722	0 00 7777.4000.0000	6745	0 00 0000.0000.0000
6723	0 00 0000.0000.0000	6746	1 00 7106.5141.5200
6724	1 00 1576.1653.0570	6747	0 00 7777.4000.0000
6725	0 00 7777.4000.0000	6750	0 00 0000.0000.0000
6726	0 00 0000.0000.0000		

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4. Block VI
5. Punched card with control sum equal to zero

Results of calculation of the parameters of a gas in the outlet section of a complex channel with $N_p = 3000$

Parameter	Calculated values of the parameters
$W_{+\lambda}$	$-+-$ 00 35301507
n'_{λ}	$-++$ 01 73347279
$V'_{3(\lambda)}$	$--+$ 01 15401366
T'_{λ}	$-++$ 01 46998838
$q'_{3(\lambda)}$	$--+$ 03 24781755

END

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